Spring 5-1993

Hydropower Group

Brian Council
University of Tennessee - Knoxville

TENNESSEE SCHOLAR SENIOR PROJECT

Submitted to: Dr. Wheeler

May 7, 1993

Brian Council

HYDROPOWER GROUP

TEAM MEMBERS:

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HYDROPOWER GROUP
DESIGN OF A WATER TURBINE

2 / 11 /93
DR PARSONS

TEAM MEMBERS:
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OBJECTIVE

WATERPOWER '93 - a hydropower industrial conference held every other year in Nashville, is sponsoring the second North American Hydro Power Contest. We plan to enter this contest in two separate categories. These categories are the Student Division, Undergraduate Class and the Open Division, Unrestricted Class. As participants of this contest, we plan to successfully achieve the contest requirement of converting the gravity potential of thirty liters of water from a vertical distance of four meters into the raising of a one-kilogram weight. This weight will be raised a vertical distance of three meters within the smallest amount of time, thus enabling our entries to win the contest. For the Student Division, Undergraduate Class entry, we will develop through extensive analysis and creativity, the most efficient method of energy conversion utilizing a turbine wheel supplied by the contest sponsors. For the Unrestricted Class entry, we plan to design and construct a second hydro-powered device which will surpass the efficiency of our first device and achieve the contest requirement of energy conversion. Participating in this contest presents a real challenge for our group to perform at the highest level, thereby achieving recognition for both ourselves and The University of Tennessee.

INTRODUCTION

The design of a hydropower system as many variables that need to be considered. For example, what type of wheel needs to be used or what size of wheel? The report identifies what areas need to be addressed and proposes a conceptual solution. The alternatives that were developed during brainstorming are included along with the advantages of each system.

DESIGN ALTERNATIVES

TRANSMISSION

Power transmission is used here to describe how the gravitational potential energy of water can be converted to mechanical power. This design team has spent many hours as a group and individually to develop ways to efficiently accomplish this task. The ideas developed can be divided into four basic areas: (1) Pulleys, (2) Belt drive systems, (3) Gear drive systems, and (4) Direct drive systems.

Several innovative pulley systems were conceived, however, a rule requiring the entire power transmission fit on a 15 X 20 inch area eliminated pulleys as an alternative. The belt and gear drive systems received similar attention with interesting ideas being presented for each. The ideas typically involved providing a variable gear ratio, which could be changed to affect power and speed for lifting the weight. One idea was to use a bait-caster fishing reel to take advantage of the precision gears and of existing technology. The team visited the TVA Engineering Laboratory in Norris Tennessee to inspect the test stand and to observe a working model. It was readily apparent that much energy can be lost through bearing friction and poorly aligned or poorly manufactured gears or belt drive systems. The team was also able be see pictures of winning entries from the previous contest. The best designs in each classification utilized a direct drive method.

This is true primarily due to the need to maintain as low an inertial mass as possible within the drive mechanism given the limited available power. Thus our proposal will utilize a direct drive mechanism. Preliminary evaluations indicate the need to minimize the inertial mass of the system to ensure positive acceleration of the spool. The spool will be attached directly to the turbine wheel to minimize torsional stresses in the shaft, thereby making it possible to use a more lightweight shaft material. A computer spreadsheet has been setup to perform parametric studies for the best combinations of nozzle size, wheel diameter, spool diameter, and other parameters such as mass. A best guess test model will be built and the Tec equipment flow-bench will be used to simulate actual conditions and to verify the computer model.

An alternative which will be explored further is to install a centrifugal clutch between the turbine and the spool. This will allow a more massive turbine wheel to generate momentum and raise the weight very quickly after clutch engagement.

NOZZLE

One of our most important design considerations for this project is the type of nozzle configuration used. Several design decisions fall under this category, including the type, orientation, quantity, and size of the nozzle(s). We decided that a simple garden hose attachment, like one used for cleaning leaves off of a driveway, would be the ideal nozzle for our project. They are cheap and readily available (no manufacturing needed), and are easily attached to our water supply line. Using blade diagrams, our group feels the best orientation of the nozzle(s) would be for the stream of water to be perpendicular to the pitch circle of the turbine. This is true for all types of turbine blades (forward-, backward-curved, and radial). As of yet, we are undecided whether to use one nozzle or multiple nozzles. I feel that one nozzle will be satisfactory if our shaft and bearing system are adequate. Two nozzles will have the same overall flow rate, but there would be more friction. In summary, we feel one garden hose nozzle oriented tangent to the turbine wheel pitch circle will suit our needs very well.

TURBINE WHEELS

There are two basic types of turbine wheels. The impulse and the reaction wheel. In the impulse class the Pelton or bucket wheel is most common. The Pelton wheel is considered a high head device with 3.5 to 4.3 specific speed. The Francis wheel is a reaction wheel and is considered a medium head wheel with 18 to 85 specific speed. Another reaction wheel is the propeller wheel which is classified as a low head wheel with 100 to 125 specific speed. The first guess would be to use the propeller wheel since it is a low head wheel. However, the problem with using the propeller or even the Francis wheel is there geometry is very complicated and would be difficult to build. This would explain why all of lasts years entries in the contest were Pelton wheels.

Another consideration of the wheel design is what size to make the wheel. Through calculations we have determined that as the wheel diameter is increased the wheel speed goes down but the torque will go up. Oviously there is and optimum point that will balance the speed vs. torque. Our objective in the open division is to build as small a wheel as possible and still lift the weight. Of course this design parameter will only apply to the open division.

Weight is another parameter of the wheel design that will affect performance. The heavier the wheel the more inertia that will need to be over come to start and accelerate the wheel. However, when a heavy wheel has reached is maximum speed it will be faster. An example is an entry in last years competition. A wheel made of brass was run in the contest. The brass wheel started slow and accelerated to a high rate of speed and power. Actually the brass wheel was moving so fast it almost broke the top of the test stand. As a comparison, another wheel was run with the opposite design philosopy using a lighter weight wheel. This wheel was made from plastic used to manufacture hearing aids. The lighter wheel accelerated faster but had a lower top speed. It is interesting to know that the lighter wheel won the contest.

The last thing to be discussed is how the open class turbine can be made. One possible solution is to make a mold for a casting. The model to be used for the casting can be carved from wood. A possible casting material is a product called castomold manufactured by United States Plastics. The process is a two compound material that is mixed together and then poured over the model to form the mold. Information from the manufacturer is included in the Appendix C.

BEARINGS

The purpose for using bearings in our design is to reduce friction. During research and visiting the TVA Engineering lab, it became apparent that reduction of friction would be important. Two basic types of bearings apply to our project: (1) ball bearings, and (2) nylon bushings. Ball bearings have the best friction reduction characteristics. However, ball bearings are the most expensive. On the other hand, nylon bushings are inexpensive, easy to find, and they do reduce friction. The problem with nylon bushings is the tighter the fit, the more friction.

TESTING

One of the most important requirements for having a successful final design is having an above average testing procedure. For our Hydro-Power Contest entry, testing could be the difference between winning and losing. Rather than build an exact replica of the official water tank and stand, which would be costly and time consuming, we have come up with several alternatives. The first was to simply put a fish tank on the stairwell platform in

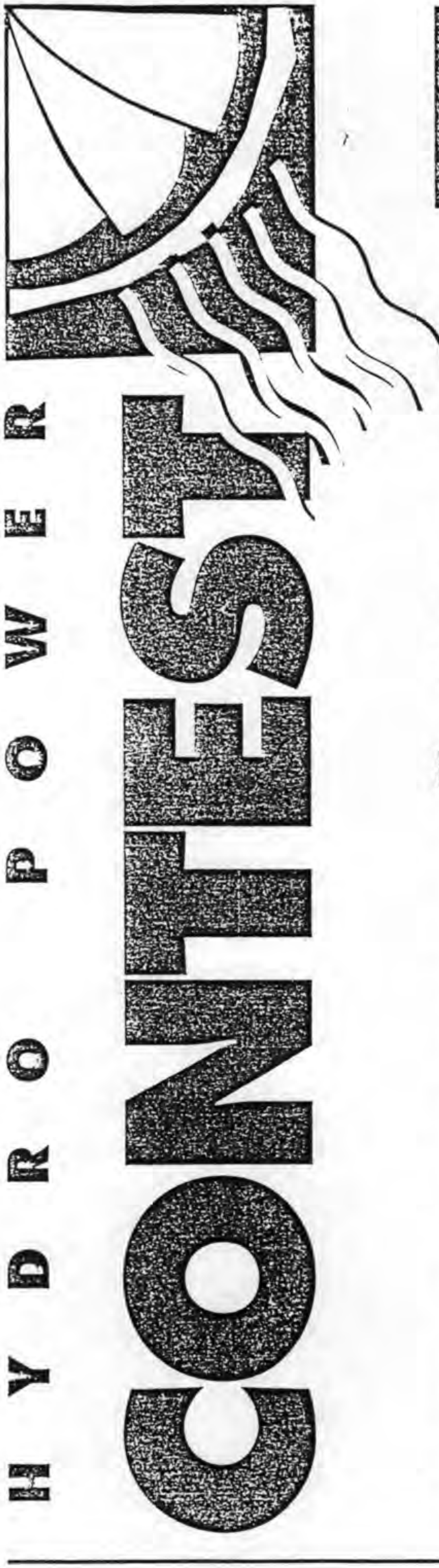
Dougherty Engineering Building. This would give us the required 4 m head. A garden hose could be run from the platform to the ground, with a pressure gage on it, to be sure we have 5 psig at the inlet. While possible, this alternative has drawbacks. First, we could not leave it there overnight, so every class we would need to set it up and take it down. Also, the stairwell does not have adequate drainage, so we would need another tank to catch the water, which could get messy. The best test would be to use the basement underneath the mezzanine in Dougherty, still using the fish tank and garden hose. This alternative could be left standing, saving us needed set up time. Also this room has a drain in the floor. Both of these reasons make this the most attractive alterative.

CONCLUSIONS AND RECOMMENDATIONS

For our conceptual design we are using a impulse turbine wheel directly coupled with a take up spool. We are recommending the wheel be cast using the Castomold system as shown in appendix C. The shaft will be a simply supported shaft with ball bearings. The power will be delivered by a single nozzle oriented horizontally and tangent to the turbine wheel pitch diameter. Initial calculations from a computer model indicate that the conceptual design follows the performance of the previous years contest winner. Our next step will be to perform physical testing to further confirm our computer model and to get additional insight on how the system will perform. The Tec Quipment flow bench and Pelton wheel in the lab will be used to perform the tests.

APPENDICES

APPENDIX A



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This information kit provides a description of the contest, an outline of the contest rules and parameters, and information on how to enter.

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Contest Description

Several industry organizations, with leadership from *Hydro Review* magazine and the Tennessee Valley Authority Engineering Laboratory, have organized the second North American Hydro Power Contest for university and college students and other interested individuals. The competition will take place during WATERPOWER '93 — a hydropower industry conference held every other year — in Nashville, Tennessee, August 10-13, 1993.

To participate in the competition, each contestant is required to construct a device that converts the gravity potential of water into mechanical power. During WATERPOWER '93, contestants' devices will be tested. In the test, the mechanical power produced will be measured by the time, in seconds, it takes to lift a weight a fixed distance. The design that lifts the weight in the shortest period of time wins the contest. This year's contest also will include an efficiency competition, which permits contestants to submit entries seeking a different objective than the"mainstream" contest. In this division, contestants' devices are to lift the weight using the minimum amount of water within a maximum time constraint of 2 minutes. A panel of industry experts will serve as contest monitors and judges.

Contestants' designs must incorporate a turbine wheel, which will be provided to contest applicants. The device may use shafts, gears, pulleys, or other mechanisms attached to the mounting board to convert the turbine power into mechanical power to lift the weight.

The contest is comprised of four divisions: student division, open division, "pro" division, and efficiency division. The first two — student and open — each have two classes:

Student Division

Undergraduate Class (for regularly enrolled full-time undergraduate students at colleges and universities; this includes high school students graduating in the spring of 1993 and enrolled in a college or university for the fall of 1993)

Graduate Class (for regularly enrolled full-time graduate students at colleges and universities; this includes undergraduate students graduating in the spring of 1993 and enrolled in a graduate program at a college or university for the fall of 1993)

Open Division

General Class (for all entrants not eligible for any of the classes in the student division)

Unrestricted Class (for any entrant—students and others) In this class, entrants aren't required to use the supplied turbine wheel. However, the motive force for lifting the weight must be developed using a water-powered turbine-type device.

The "Pro" and Efficiency Divisions are new additions to the 1993 Hydro Power Contest:

"Pro" Division

This new division is only open to prior winners (1st, 2nd, and 3rd place winners) of either the Student or Open Division awards. To enter this division, contestants' devices must be of the "unrestricted" variety. The same rules for the Open Division, Unrestricted Class apply. Prior winners are not allowed to participate in the same class(es) as in 1991.

Efficiency Division

The objective of the competition is to lift the weight using the minimum amount of water within a maximum time constraint of 2 minutes. To enter this division, contestants' devices must be of the "restricted" variety — they must use the provided turbine wheel. This division is open to any contestant.

Prizes

More than $20,000 in scholarships, cash, and prizes will be awarded to participants in the 1993 Hydro Power Contest. Prizes for first place winners include:

Student Division
(both Undergraduate and Graduate Classes)

- Scholarship Awards: top winners will receive substantial scholarship awards from the U.S. Department of Energy and others
- $1,000 Cash
- Hewlett-Packard HP 48SX scientific calculator

Open, Pro, and Efficiency Divisions

- $1,000 Cash
- Hewlett-Packard HP 48SX scientific calculator

Additional prizes will be awarded to 2nd and 3rd place winners in each division. Winners will be publicized in *Hydro Review*. All competitors will receive a free one-year subscription to *Hydro Review*.

How to Enter

To enter, contestants should send an entry fee of $15, payable to Hydro Power Contest, along with their name, address, and daytime telephone number, to: Hydro Power Contest, c/o *Hydro Review*, 410 Archibald Street, Kansas City, MO 64111.

Entries can be from either individuals or teams. An entry may be entered in any class in any division for which it is eligible, but may compete in only one class. For each division entered, the contestant must construct a new device. A contestant can enter a maximum of two devices. Entries will be accepted until May 15, 1993.

Entrants will receive a contest kit: a turbine assembly, an extra turbine wheel, a copy of the contest rules (this information kit), and a complimentary copy of *Hydro Review*.

For more information about the contest, contact *Hydro Review* at (816) 931-1311; FAX: (816) 931-2015.

Technical Advisory Committee

Members of the contest's technical advisory committee developed the contest parameters, and will serve as technical advisers for the contest.

Committee members are:

— Michael Coates, senior engineer, New England Power Service Company and former contest participant

— John Gulliver, PhD, professor and researcher, St. Anthony Falls Hydraulic Laboratory, University of Minnesota

— Patrick March, senior mechanical engineer at the TVA Engineering Laboratory, Tennessee Valley Authority

— Lee Sheldon, senior hydropower specialist, Bonneville Power Administration

Contest Rules & Parameters

1) Each entrant must construct a mechanical mechanism to convert water power into mechanical movement. During the competition in the Student, Open, and Pro Divisions, each contestant's water turbine-powered device will be tested to see which entry can succeed in most quickly lifting a fixed weight (1 kilogram) a specified vertical distance (3 meters). In the Efficiency Division, each contestant's water turbine-powered device will be tested to see which entry can lift a fixed weight (1 kilogram) a specified vertical distance (3 meters) with the least amount of water.

2) The measure of mechanical power produced will be the time, in seconds, required for the contestant's device to lift the weight to the 3-meter vertical height. The number of seconds required to lift the weight will be the contestant's score. The entry in each division and/or class in the Student, Open, and Pro Divisions with the lowest score will win the contest. For the Efficiency Division, time and flow rate will be continuously monitored and integrated to give the volume of water used to lift the weight. The entry that uses the least amount of water will win the contest.

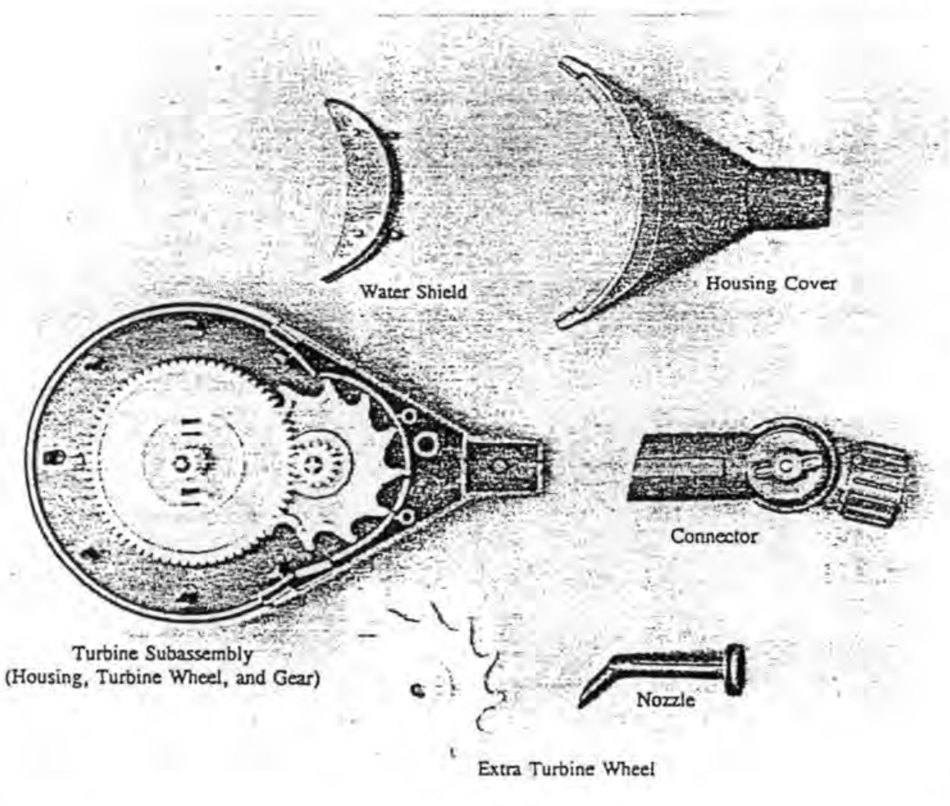


Figure 1

3) Each entrant in the contest will be supplied with a water turbine assembly and one extra turbine wheel. Any and all parts of this assembly can be used by the entrant. (See Figure 1 for turbine components.) However, as a minimum, the turbine wheel must be used, and only one turbine wheel may be used for each entry. No such limitations apply in the unrestricted class of the Open Division or in the Pro Division.

4) No modification of the turbine wheel supplied is allowed other than cleaning up the wheel to remove molding marks and flashing. All other parts of the turbine assembly may be eliminated or extensively modified. Contestants are not restricted to using the supplied gears and bearings.

5) In the Unrestricted Class and Pro Division competitions, the requirement to use the supplied turbine wheel is waived. However, some type of turbine device must be used for converting the water power to mechanical power.

6) All motive force produced by the contestant's device for lifting the weight must come from the potential and kinetic energy of the water that flows through the device.

7) No electrical or electronic items may be part of a contestant's device.

8) During the competition event at the WATERPOWER '93 conference, a representative of each entry must be present to set up the device that is entered for testing. If an entrant cannot arrange for a representative to be present, *Hydro Review* will, upon request, seek to arrange for representation.

9) Each entry representative will be allowed a maximum time of 15 minutes. This includes setting up the device for testing, making trial runs and doing adjustments, completing a maximum of two competition runs, and disassembly. Contestants cannot touch the device during competition runs. Contestants must advise the contest judges regarding which runs are competition runs before the runs begin.

10) In the test, up to 30 liters of water will be allowed to flow from a 4-meter elevation through a conduit (a 1/2-inch inside diameter polyethylene tube). The water will pass through the contestant's device. The device, in turn, will lift a 1 kilogram weight vertically 3 meters. A sump beneath the testing apparatus will collect water flowing out of the device. Figure 2 is a scale drawing of the testing apparatus with various instructions.

11) The contestant's assembly shall be on a mounting board that is 51

centimeters (20 inches) wide and 38 centimeters (15 inches) in height. The mounting board shall be 1/2 inch thick.

12) The mounting board will be affixed to the mounting rails on the testing apparatus with clamps, furnished at the test location. The centerline of the contestant's runner will be placed at a fixed elevation on the test stand. When mounted on the test stand, no part of the contestant's device — with the exception of the take-up line — may extend beyond the edges of the mounting board. Figure 2 illustrates where the mounting board fits on the testing apparatus.

13) When mounted for testing, the turbine shaft can be in any configuration. The centerline of the runner in any configuration (vertical or horizontal) shall be equal to the elevation of the centerline of the inlet valve.

14) No means of storing mechanical energy in the device or take-up line prior to its operation by water will be allowed.

15) When mounted, the contestant's turbine will be connected to the test apparatus with a garden hose-type pigtail (for supplying water to the contestant's device) and through a fish line connector (to connect the contestant's cord to the fish line that is attached to the 1 kilogram weight). The pigtail and fish line connector will be furnished at the test location.

16) For the test, each contestant must supply the turbine and a motion translator (take-up) device, including a fish line (or similar cord) for connection to the weight lifting line. The connector line must be at least a 17 pound test fishing line (monofilament or equivalent) and be 4 meters long. (See Figure 2). The fish line take-up should be perpendicular to the mounting board for best performance.

17) The contestant's device shall include a standard garden hose type female connector (mounted horizontally) for connection to the water supply on the testing apparatus. (See Figure 2).

18) Prior winners of the Hydro Power Contest are not allowed to participate in the class(es) that they entered in 1991.

19) At the option of contest judges, devices are subject to impoundment for examination prior to being returned to contestants. In the event of a dispute, the opinion of the judges is final.

20) Devices shall remain at the contest booth for display after the contest runs until the conclusion of WATERPOWER '93, at which time the devices will be retrieved by the contestants.

21) The foregoing rules are subject to change at any time.

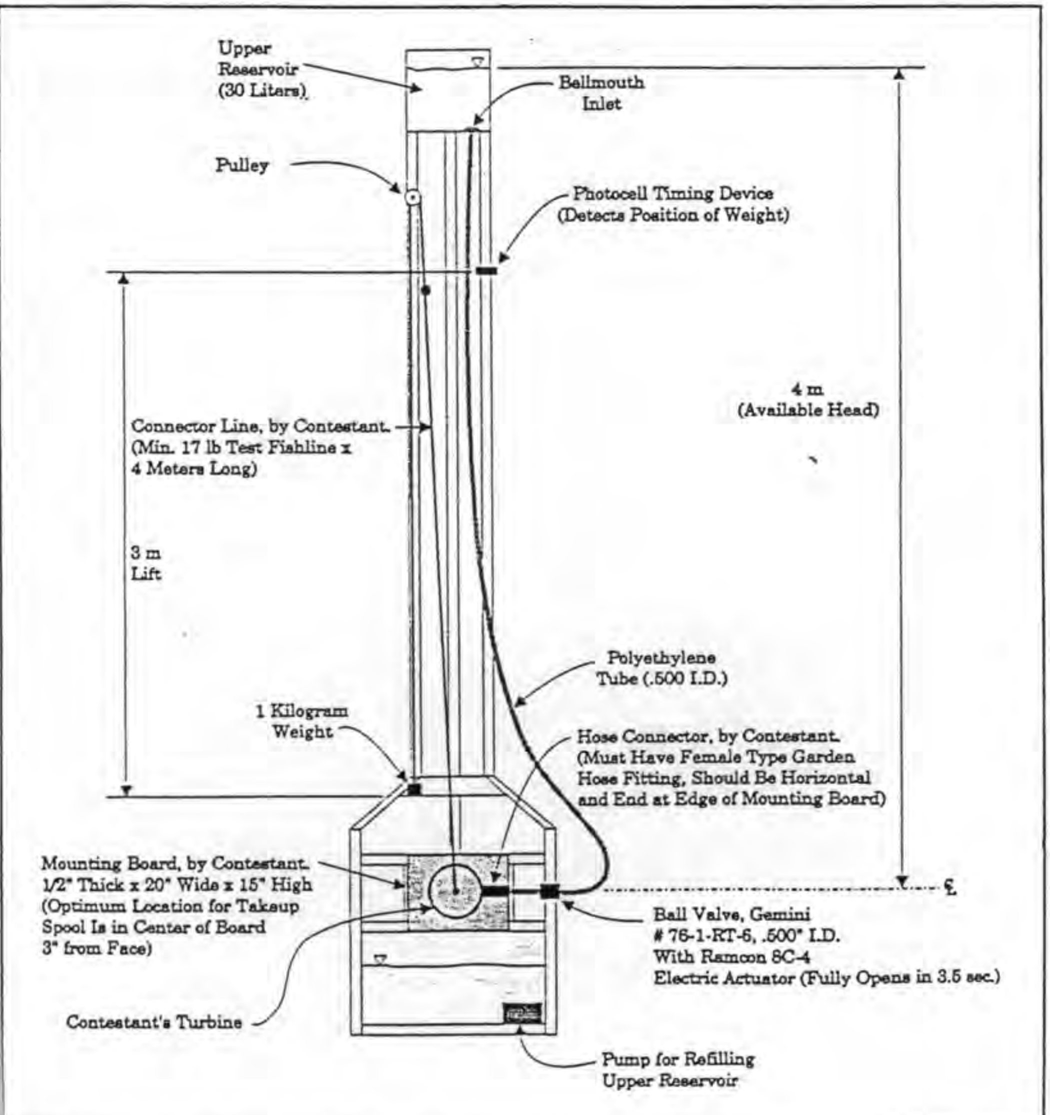


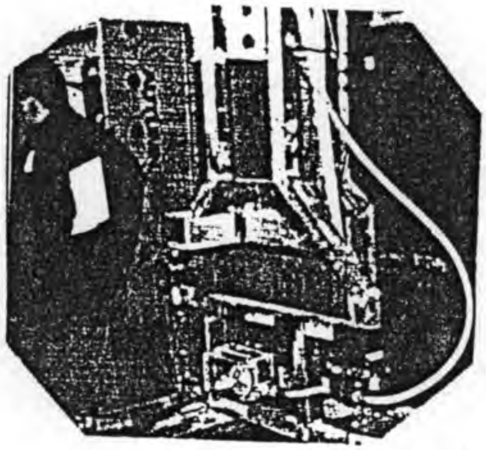
Figure 2

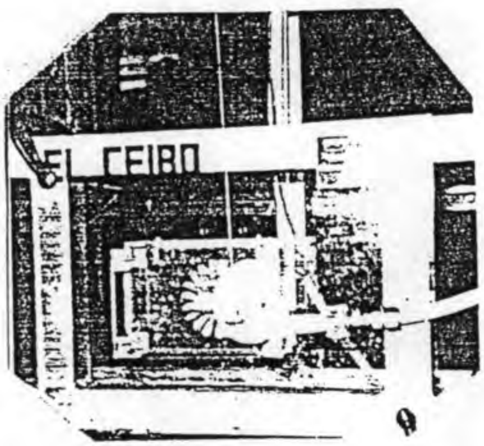
Notice: The turbine device supplied to contestants for use in this contest was manufactured by Swirlon International and is protected by certain patents. The use of the Swirlon device by contest participants for contest purposes does not convey to participants any license or rights to Swirlon's registered and pending patents.

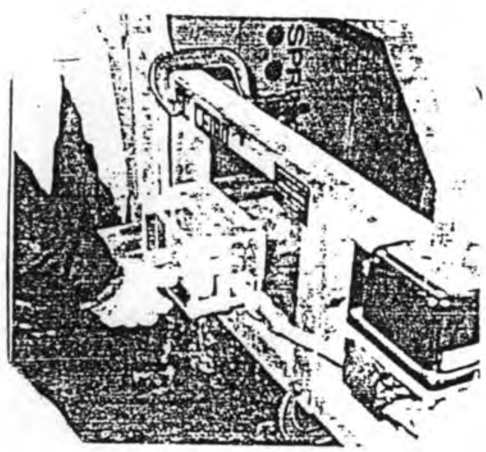
For additional copies of this information kit, contact:

Hydro Power Contest
c/o *Hydro Review*
410 Archibald Street
Kansas City, MO 64111
PHONE (816) 931-1311
FAX: (816) 931-2015

APPENDIX B







LAST YEARS ENTRY

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39011 Translucent Color Kit - 6 Colors	Ea. $ 8.49

Opaque Kit Contains: ½ oz. ea. Red, Blue, Yellow, White, Black, Brown. Each jar will color approximately 1-gallon of Castolite. Translucent Kit Contains: Blue, Green, Yellow, Amber, Purple and Red.

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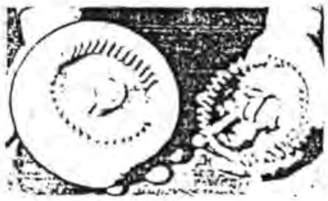
Castomold is a flexible molding plastic developed for making Castolite castings. It is a low viscosity compound which has very fine reproduction qualities from an original pattern. A hardener is used to "set" the plastic for a mold; it is normally hard within an hour. A Castolite is good for 3 to 10 Castolite castings. Complete directions are supplied with the material.

2. Removing pattern from mold



3. Removing duplicate made from Castolite from mold.

39004 1-Pint with Hardener	Ea. $13.29
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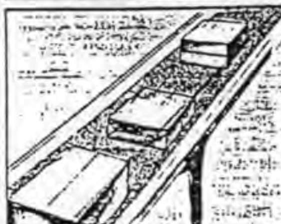

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5/8	39104	$ 21.71	39116	$ 27.12	39128	$ 41.45
3/4	39105	$ 26.05	39117	$ 32.54	39129	$ 49.74
7/8	39106	$ 30.39	39118	$ 37.97	39130	$ 58.03
1	39107	$ 34.73	39119	$ 43.39	39131	$ 66.32
1-1/2	39108	$ 52.10	39120	$ 65.09	39132	$ 99.48
2	39109	$ 69.46	39121	$ 86.79	39133	$132.64
3	39110	$104.20	39122	$130.18	39134	$ 198.96
4	39111	$138.93	39123	$173.57	39135	$ 265.29
6	39112	$208.39	39124	$260.36	39136	$ 397.93
9	39137	$312.59	39140	$390.54	39143	$ 596.89
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Does Not Contain Methylene Chloride

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39012	Ea. $4.28

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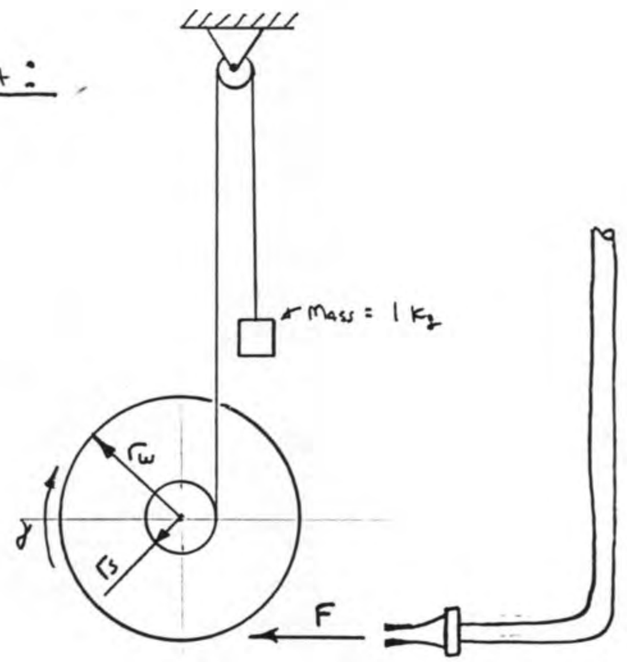
PURPOSE: Outline equations to model the system for parametric studies.

ASSUMPTIONS: See list ~~Later~~

Given:
Head = 4 m
Vol. = 30 L
Supply = 0.5 IN ID
Lift = 3 m

SKETCH:



ANALYSIS:

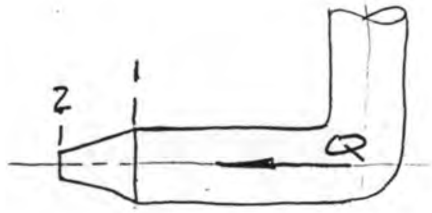
Break into pieces:

A) Size Nozzle; Find: V_1, V_j, Q, F

B) Model wheel / spool; Find: I_o

C) Find: α

A)



$Q = A_1 V_1 = A_2 V_2$

$Z_1 = Z_2$

$P_2 = 0$

Bernoulli: $\cancel{Z_1} + \frac{V_1^2}{2g} + \frac{P_1}{\gamma} = \cancel{Z_2} + \frac{V_2^2}{2g} + \cancel{\frac{P_2}{\gamma}}^{\,0}$

$A_1 = \frac{\pi D_1^2}{4}$; $A_2 = \frac{\pi D_2^2}{4}$

$$\frac{\pi D_1^2}{\cancel{4}} V_1 = \frac{\pi D_2^2}{\cancel{4}} V_2 \Rightarrow \boxed{V_1 \left(\frac{D_1}{D_2}\right)^2 = V_2}$$

$P_1 = \rho g h = \gamma h$

$$\therefore \frac{V_1^2}{2g} + h = \frac{V_2^2}{2g}$$

$$V_1^2 - V_2^2 + 2gh = 0$$

$$V_1^2 - V_1^2 \left(\frac{D_1}{D_2}\right)^4 = -2gh$$

$$V_1^2 = \frac{-2gh}{\left(1 - \left(\frac{D_1}{D_2}\right)^4\right)}$$

$$\boxed{V_1 = \sqrt{\frac{-2gh}{\left(1 - \left(D_1/D_2\right)^4\right)}}}$$

ex; Say; $D_1 = 0.5$ in, $D_2 = 0.25$ in, $h = 13.1232$ ft
$g = 32.174$ ft/sec²

$V_1 = 7.503$ ft/sec ✓ Spreadsheet Agrees

$V_2 = 30.0125$ ft/sec ✓

$$Q = A_1 V_1 = \frac{\pi D_1^2}{4} V_1 = \frac{\pi \left(D_1/12\right)^2}{4} V_1 \Rightarrow Q = 0.01023 \text{ ft}^3/\text{sec} ✓$$

$$F = \rho Q V_2 = \left(1.936 \frac{\text{slugs}}{\cancel{\text{ft}^3}}\right)\left(\frac{\text{lb} \cdot \text{s}^2}{\cancel{\text{ft}} \cdot \cancel{\text{slug}}}\right)\left(0.01023 \frac{\cancel{\text{ft}^3}}{\cancel{\text{sec}}}\right)\left(30.0125 \frac{\cancel{\text{ft}}}{\cancel{\text{sec}}}\right)$$

see pg 4 ⇒ $F = 0.594$ lbf ✓

A) cont. Use Torricelli's Eqn. { Ref "White" Eq. 11.40

Jet Velocity : $V_j = C_v \sqrt{2gh}$ $\qquad 0.92 \le C_v \le 0.98$

if $C_v = 6\% = 0.94$

$$V_j = 0.94 \sqrt{(2)(32.174 \text{ ft/sec}^2)(13.1232 \text{ ft})}$$

$\underline{V_j = 27.32 \text{ ft/sec}}$ ✓ Spreadsheet Agrees

Look @ Optimum conditions for Pelton Wheel.

Ref. "White" Pg. 666 → 671.

$$N_{sp} \approx 4.5 = \frac{(Rpm)(bhp)^{\frac{1}{2}}}{(h)^{1.25}}$$

P_w = Water horsepower = $\gamma Q h = \left(62.3 \frac{lbf}{\cancel{ft^3}}\right)\left(0.01023 \frac{ft^3}{sec}\right)(13.1232$

$$P_w = 8.364 \frac{lbf \cdot ft}{sec} \left(\frac{hp}{550 \text{ lbf} \cdot \frac{ft}{sec}}\right)$$

$\underline{\underline{P_w = 0.0152 \text{ hp}}}$

IN SI UNITS

$$\gamma Q h = \left(\frac{N}{m^3}\right)\left(\frac{m^3}{s}\right) m = \frac{N \cdot m}{s} = \frac{J}{s} = W$$

$$= \cancel{W}\left(\frac{1.341 \text{ hp}}{1000 \cancel{W}}\right)$$

$bhp = \omega T$

$\eta = \frac{P_w}{bhp} = 85\%$ max

$bhp = \omega T = \frac{P_w}{0.85} = \underline{\underline{0.0179 \text{ hp} = bhp}}$

$$\frac{4.5\,(h)^{1.25}}{(bhp)^{\frac{1}{2}}} = RPM = \frac{(4.5)(13.1232 \text{ ft})^{1.25}}{\sqrt{0.0179 \text{ bhp}}}$$

$$\underline{\underline{RPm = 840 \frac{rev}{min} = 14 \frac{rev}{sec}}}$$

Φ = peripheral-velocity factor $= \dfrac{U}{\sqrt{2gh}} = 0.47$

$U = \pi n D$

$$D = \frac{(0.47)\sqrt{(2)(32.174\ \text{ft/sec})(13.1232\ \text{ft})}}{\pi\left(14\ \frac{\text{rev}}{\text{sec}}\right)}$$

$\underline{\underline{D = 0.31\ \text{ft} = 3.7\ \text{IN}}}$

$U = \pi(14\ \text{rev/sec})(3.7\ \text{IN}) \Rightarrow U = 168.9\ \text{IN/sec}$

$\underline{\underline{U = 13.658\ \text{ft/sec}}}$

$F = \rho Q (V_j - U)(1 - \cos\beta)$

$$F = \left(1.936\ \frac{\text{slugs}}{\cancel{\text{ft}^3}}\right)\left(0.01023\ \frac{\cancel{\text{ft}^3}}{\cancel{\text{sec}}}\right)\left(27.32\ \frac{\cancel{\text{ft}}}{\cancel{\text{sec}}} - 13.658\ \frac{\cancel{\text{ft}}}{\cancel{\text{sec}}}\right) *$$

$$\left(1 - \cos 165^\circ\right)\left(\frac{\text{lb}\cdot\cancel{\text{s}^2}}{\cancel{\text{ft}}\cdot\cancel{\text{slug}}}\right)$$

$\underline{\underline{F = 0.532\ \text{lb}}}$

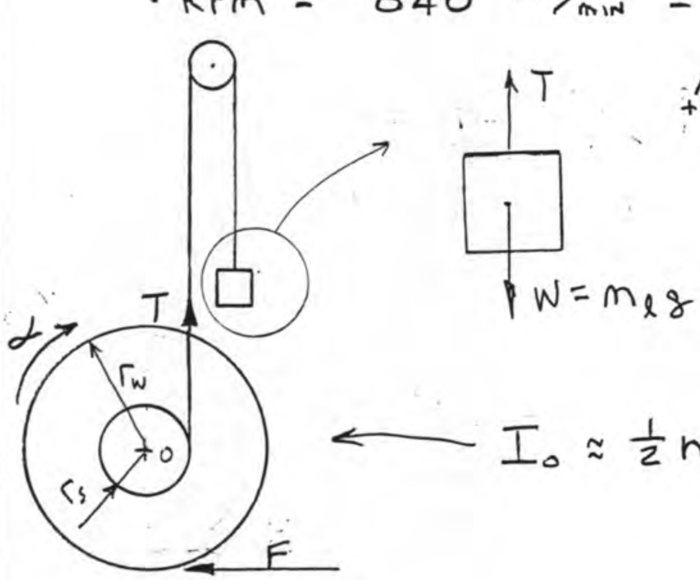
Power to wheel $= P = FU = (0.532\ \text{lb})\left(13.658\ \frac{\text{ft}}{\text{sec}}\right)\left(\dfrac{\text{hp}}{550\ \frac{\text{lb}\cdot\text{ft}}{\text{sec}}}\right)$

$\underline{\underline{P = 0.0132\ \text{hp delivered to wheel}}}$

B) Model Wheel / Spool :

Found in Part A) ;

- $U = 168.9$ in/sec $= 13.658$ ft/sec
- $F = 0.532$ lb
- $P = 0.0132$ hp
- $D = 0.31$ ft $= 3.7$ in $\Leftarrow$ $r_w = 1.86''$
- $Rpm = 840$ rev/min $= 14$ rev/sec



$+\uparrow \Sigma F = m a_y$

$T = m_\ell g + m_\ell a_y \quad (1)$

$a_y = r_s \alpha \quad (2)$

$I_o \approx \frac{1}{2} m_T r_w^2$

$+\circlearrowright \Sigma \overline{M}_o = I_o \alpha$

$F r_w - T r_s = \frac{1}{2} m_T r_w^2 \alpha$

$T r_s = F r_w - \frac{1}{2} m_T r_w^2 \alpha$

$T = F\left(\frac{r_w}{r_s}\right) - \left(\frac{1}{2 r_s}\right) m_T r_w^2 \alpha \quad (3)$

$m_\ell g + m_\ell r_s \alpha = F\left(\frac{r_w}{r_s}\right) - \left(\frac{1}{2 r_s}\right) m_T r_w^2 \alpha$

$\alpha \left(m_\ell r_s + \left(\frac{1}{2 r_s}\right) m_T r_w^2\right) = F\left(\frac{r_w}{r_s}\right) - m_\ell g$

$$\alpha = \frac{F r_w - m_\ell r_s g}{\frac{1}{2} m_T r_w^2 + m_\ell r_s^2} \quad (4)$$

$$\alpha = \frac{(0.532\ \text{lb})(2.5\ \text{in}) - (2.204622\ \text{lbm})(0.75\ \text{in})(386\ \text{in}/\text{s}^2)}{\frac{1}{2}(0.440924\ \text{lbm})(2.5\ \text{in})^2 + (2.204622\ \text{lbm})(0.75\ \text{in})^2}$$

$$\alpha = \frac{(1.33\ \text{in}\cdot\text{lb}) - 638.238\ \frac{\text{lbm}\cdot\text{in}^2}{\text{s}^2}\left(\frac{\text{lbf}\cdot\text{s}^2}{386\ \cancel{\text{lbm}}\cdot\cancel{\text{in}}}\right)}{2.168\ \text{lbm}\cdot\text{in}^2}$$

$$\alpha = \frac{-0.323\ \cancel{\text{in}\cdot\text{lb}}}{2.168\ \cancel{\text{lbm}}\cdot\cancel{\text{in}^2}}\left(\frac{386\ \cancel{\text{lbm}}\cdot\cancel{\text{in}}}{\cancel{\text{lbf}}\cdot\text{s}^2}\right)$$

@ $h = 5$ m, $\alpha \approx +16.89$ for $r_s = 0.5''$, $r_w = 1.75''$, $m_T = 0.2$

$$\underline{\underline{\alpha = -47.62\ \text{rad}/\text{s}^2}}$$ ⇐ Agrees w/ spreadsheet for the 4 meter head

$$S = \cancel{S_0}^{0} + \cancel{V_0 t}^{0} + \frac{1}{2} a_y t^2 = 3\ \text{meters} = 9.8424\ \text{ft} = \underline{118.1\ \text{in}}$$

$$a_y = r_s \alpha = (0.5\ \text{in})(16.89\ \text{rad}/\text{s}^2)$$

$$a_y = 8.445\ \text{in}/\text{s}^2$$

$$\therefore\quad 118.11\ \text{in} = \frac{1}{2}(8.445\ \text{in}/\text{s}^2)\,t^2$$

$$t = \sqrt{\frac{118.11\ \text{in}}{4.2225\ \text{in}/\text{s}^2}}$$

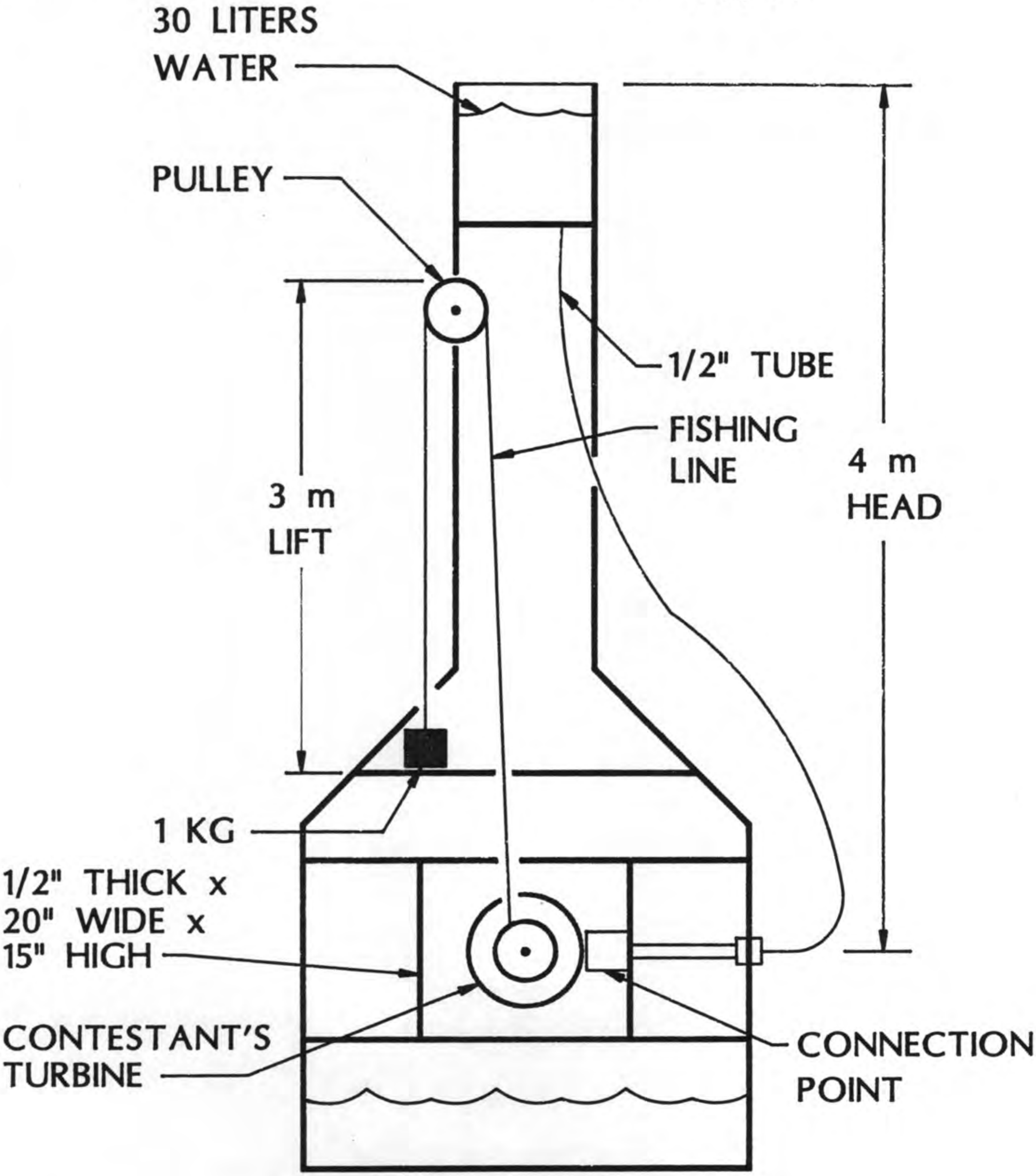
$$\boxed{t = 5.28\ \text{sec}}$$

Note: This does not include friction. It was also determined by assuming 85% eff. of wheel, nozzle losses of 6%, & $N_{sp} = 4.5$. $\therefore$ This time is similar to our target of 7.5 seconds w/ 5 meter head.

```
==================================================================
 PARAMETERS         SI           ENGLISH            COMMENTS
==================================================================
Head (H)   =        5 meter     16.404 feet
Vol (V)    =       30 liter     7.9251 gal
Pipe (D1) = 0.012700 meter         0.5 inch
Nozzle(D2)= 0.006350 meter        0.25 inch
  Area P =  0.000126 m^2      0.001363 ft^2
  Area N =  0.000031 m^2      0.000340 ft^2
Spec. Wt. =      9789 N/m^3        62.3 lbf/ft^3  <<<< 20(C), 70(F)
Density   =     998.2 kg/m^3      1.936 slug/ft^3 <<<< 20(C), 70(F)
    g =          9.81 m/s^2      32.174 ft/sec^2
   loss =           6 percent         6 percent   <<<< Nozzle loss
   BETA =         165 degrees       165 degrees   <<<< Bucket angle
   BETA =  2.879793 radians  2.879793 radians   <<<< Bucket angle
W. Radius = 0.044450 meter         1.75 inch      <<<< Wheel Radius
S. Radius = 0.012700 meter          0.5 inch      <<<< Spool Radius
Mass lift =         1 kg       2.204622 lbm
Mass Wheel =     0.25 kg       0.551155 lbm
   lift =           3 meter      9.8424 feet     118.1088 inches
   PHI =         0.47              0.47           <<<< Vel. factor
Wheel Eff =      0.85              0.85           <<<< Efficiency
==================================================================
==================================================================
The following section assumes no dynamic losses and that nozzle
is horizontal.  Bernoulli is utilized.
==================================================================
    P1  =       48945 Pascal   7.097008 lbf/in^2
(D1/D2)^2 =         4                 4
    V2 =            4 * V1            4 * V1
    V1 =     2.557342 m/s      8.388740 ft/sec   <<<< PIPE VELOCITY
    V2 =     10.22936 m/s      33.55496 ft/sec   <<<< JET VELOCITY
     Q =     0.000323 m^3/s    0.011438 ft^3/sec
     Q =     19.43744 L/min    5.134099 GPM
   time =    92.60476 sec      92.61720 sec      <<<< TANK EMPTY
     F =     3.307915 Newton   0.743064 lbf

==================================================================
==================================================================
The following section uses the Torricelli equation with a velocity
coefficient, Cv, to account for losses through the nozzle.
==================================================================
    Cv =         0.94              0.94          <<<< VEL. COEFF.
    Vj =     9.310271 m/s      30.54008 ft/sec   <<<< CORRECTED VEL
     F =     3.010702 Newton   0.676300 lbf      <<< REACTION FORCE
     U =     4.574451 m/s      15.00537 ft/sec   <<<< BUCKET VEL.
Note, bucket velocity was calculated by rearranging eq 11.38 White
page 666.  I used the nozzle reaction force in the equation.  Need
to determine if appropriate.  F = rho * Q * Vj.

==================================================================
==================================================================
The following section pertains to the Turbine:
==================================================================
   Nsp =          4.5               4.5          <<<< SPECIFIC SPEED
```

```
    Pw =     0.021263 hp          0.021253 hp         <<<< WATER HP
   bhp =     0.025015 hp          0.025004 hp         <<<< BRAKE HP
   RPM =      XXXXXXX             939.4843 rpm
    D =                           0.310421 ft         <<<< PITCH DIA.
    D =                           3.725060 in         <<<< PITCH DIA.
    U =                           15.27004 ft/sec     <<<< WHEEL SPEED
    F =                           0.664778 lb         <<<< FORCE
    P =                           0.018456 hp         <<<<POWER TO WHEEL
  ALPHA =                         16.89158 rad/sec^2
Note: Alpha here was determined using an input value for the wheel
      radius, instead of the value determined above for max. eff.

    Ay =                          8.445793 in/sec^2
   TIME =                         5.288541 seconds    <<<< LIFT TIME
```

APPENDIX E



TEST STAND

HYDROPOWER GROUP

PRELIMINARY DESIGN REPORT

TEAM MEMBERS:

STEVE HUNGATE
SUSAN GARRETT
BRIAN COUNCIL
CLAUD MONROE

TABLE OF CONTENTS

INTRODUCTION:

This preliminary design report documents the status of the ME-479 Hydro-Power design group. This report includes a summary of the testing activities completed thus far, drawings depicting preliminary designs for both the open and restricted classes, and the future plans for the project.

TESTING:

Since the last report much progress has been made in the area of testing. A test stand has been erected in the basement of Dougherty Engineering Building, which is similar to the actual apparatus utilized in the competition. Also, the Tech Quipment Flow Bench and Pelton Wheel located in the Eastman Laboratory have provided unique insight into the relationship between spool diameter and lift-time.

Tests were conducted to determine pressure and flow rate for a range of nozzle sizes using the test stand and the Pelton Wheel. The data collected was then used to conduct tests on the Flow Bench. The purpose of the flow bench tests were to determine the required lift-time versus take-up spool radius for various nozzle sizes.

The following data was determined using the test stand, the pelton wheel, a stop watch and a 1/2 gallon container:

NOZZLE POSITION	PRESSURE (PSIG)	FLOW RATE (GPM)
8	0.8	4.37
7	1.0	4.16
6	1.1	4.19
5	1.3	4.12
4	1.55	3.76
3	2	3.59
0	5.5	0
P.W. Not Attached	Atm.	4.8

The following data was determined by using the flow bench,
ton wheel, weights with line and a pulley, and a stop watch.
pressures and nozzle settings determined in the test on the
nd were utilized in this test.

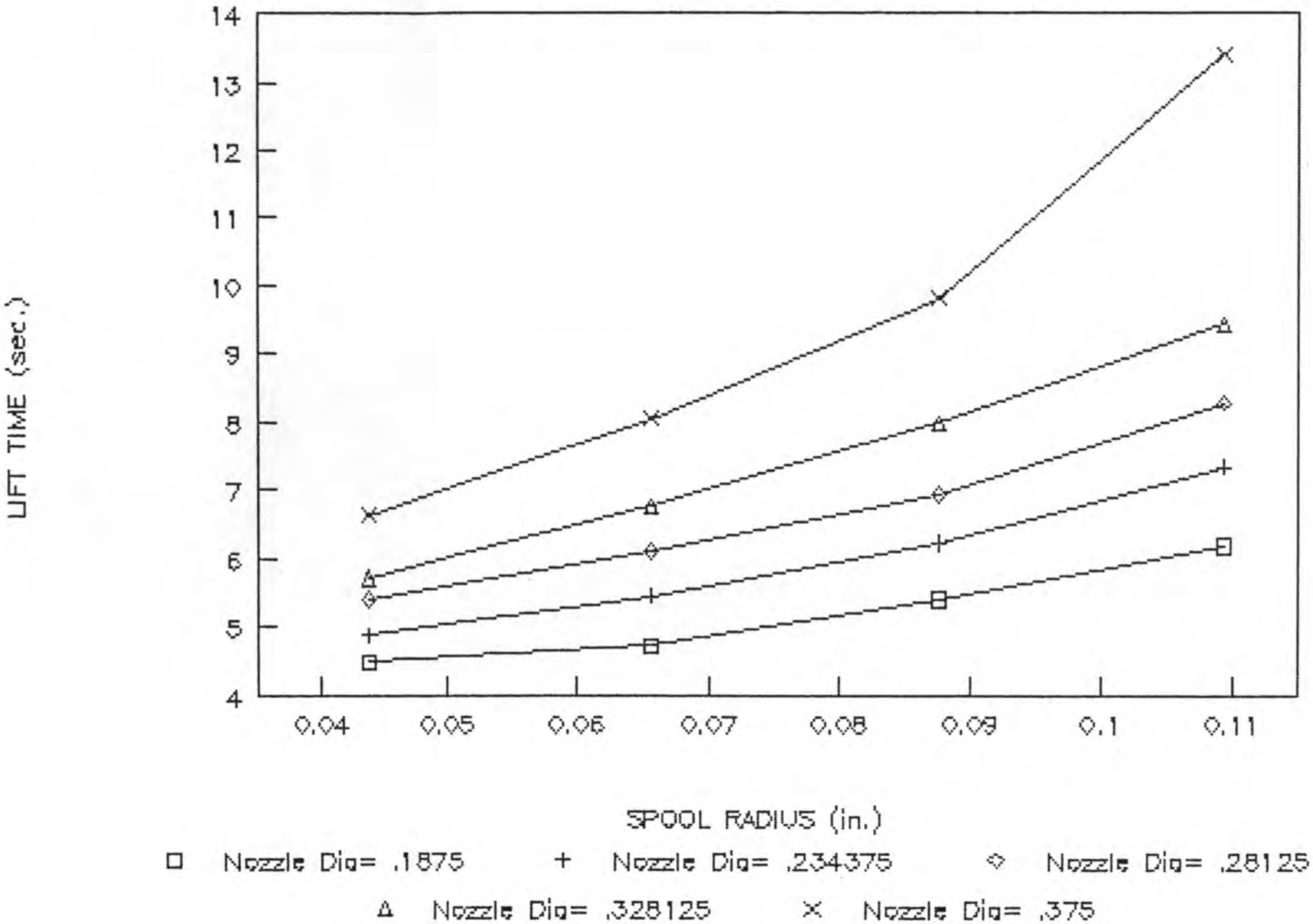
SITION	4	5	6	7	8
MASS	LIFT TIME (SEC)				
100	4.48	4.87	5.4	5.71	6.63
150	4.71	5.45	6.10	6.76	8.04
200	5.40	6.22	6.93	7.97	9.82
250	6.18	7.34	8.28	9.44	13.41
270	ND	ND	ND	10.47	STALL
280	ND	ND	ND	12.15	
300	7.31	9.08	STALL	STALL	
350	9.28	16.84			

Graphs presented on the following pages indicate the tionship between spool radius and lift-time, and nozzle eter and the dynamic force acting on the vane. Both graphs rmine the best nozzle diameter to be 0.1875 inches when using Pelton Wheel. The Pelton Wheel has a runner diameter of 3.5 es. The recommended take-up spool diameter is 0.25 inches. combination results in a lift-time of less than 7 seconds, h is very good when compared to the open class winner from the ious competition. The previous winner was at 7 seconds, but test allowed a higher head tank than we are using.

Tests for the restricted class entry are still in the overy stage, therefore, there is nothing substantial to report.

SPOOL RADIUS vs. LIFT TIME

PELTON WHEEL



DESIGN:

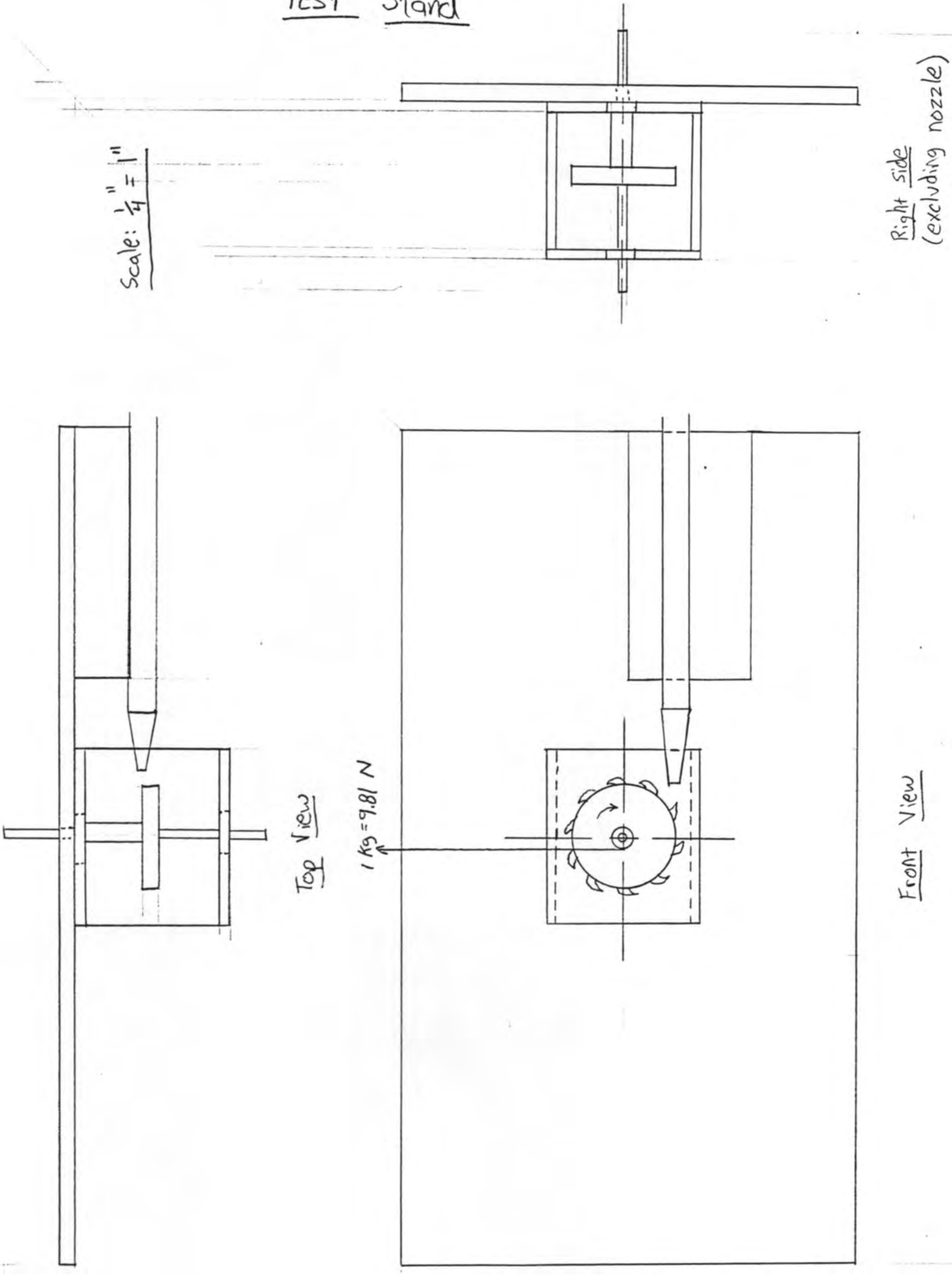
RESTRICTED CLASS:

The biggest challenge our group will face this semester is probably the restricted class entry in the Hydro Power Contest. The reason for this is simple: the turbine wheel supplied by the contest is unimpressive, to say the least. A properly designed Pelton wheel, by our calculations, would be many times more efficient. However, since we are stuck with this wheel, several good ideas on how to raise the 1 kg weight have been put forth.

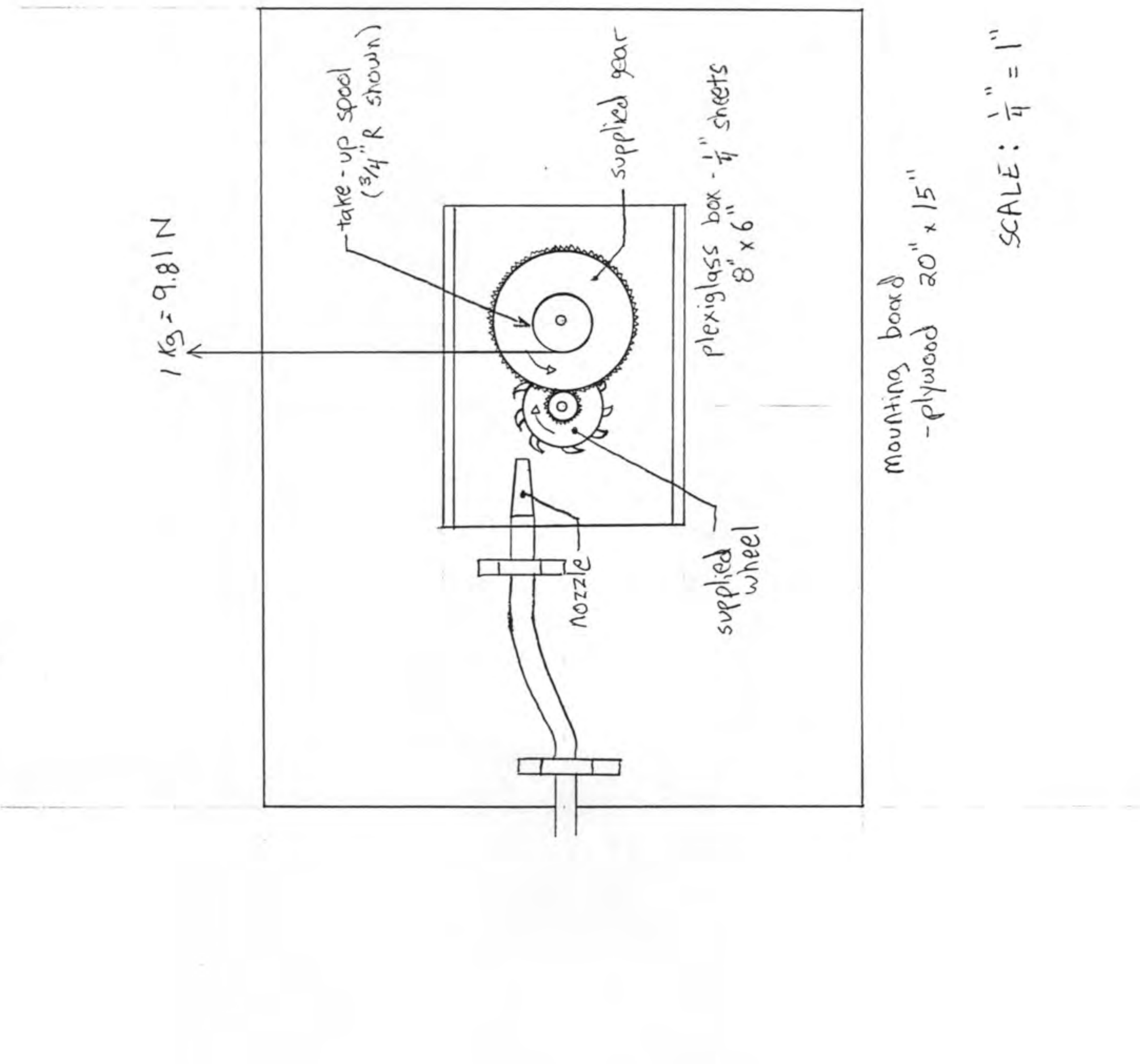
Our first task was to put together a mounting board for the supplied wheel. A 24" x 13" piece of plywood was used for this purpose. A cube approximately 5" a side made of plexiglass was used to support the bearings. The bearings were just simple ball bearings (5/8" OD) acquired from the electronics lab on the Mezzanine. The main machine shop made a shaft for the supplied wheel out of a low-carbon steel, and all this was attached to the mounting board. A three view drawing later in the report shows this more clearly. Finally, an ordinary garden nozzle was fastened to the mounting board, and we were ready to begin testing.

Our initial tests on the supplied wheel, using a head of 4 m, showed that a direct drive system (our first choice for power transmission) would not lift anywhere near the required 1 kg weight. The wheel supplied simply is not a good enough design to do this without some type of gear reduction, even with a very small take-up spool. With this in mind, we decided we need to use the supplied wheel and large gear to reduce the amount of torque needed

Current Restricted Class Test Stand



Proposed Restricted Class Entry



to lift the weight. The mounting board for this set-up will be very similar to the original one, except there will be two shafts instead of one. A sketch of this proposed power transmission system is given later in the report. We feel that this solution is the simplest way to lift the 1 kg weight.

UNRESTRICTED CLASS:

The preliminary design for the unrestricted class utilizes a Pelton wheel configuration. The Pelton wheel is 2.5 inches in diameter x 0.25 inch thick with it's cups fabricated from Alumilite Casting Plastic. The cups are secured to the runner with 0.125 inch OD screws through the cups and the runner. Also, indentions are cut into the runner for each cup and held with crazy glue to ensure attachment. The wheel is mounted onto a 0.25 inch OD stainless-steel shaft. To support testing, two additional Pelton wheels have been built which can be easily interchanged onto the shaft. The second wheel has a diameter of 3.5 inches and the third has a diameter of 5.0 inches.

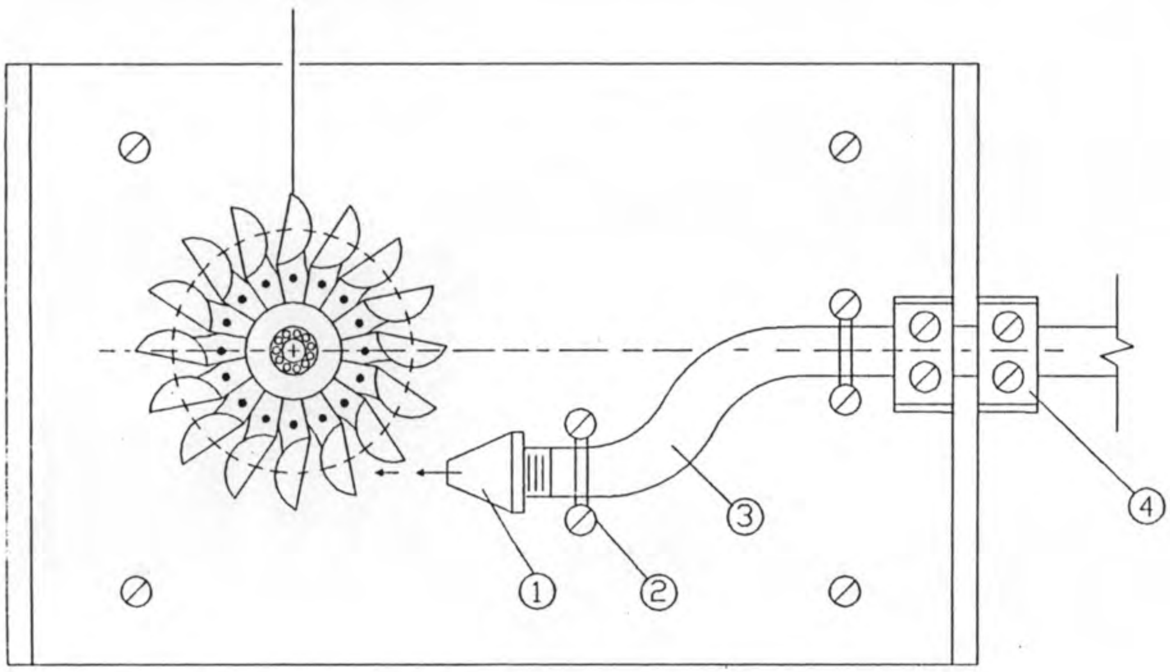
In order to incorporate a take-up spool into the design we have found that a reduction in spool diameter provides maximum benefit. Therefore, instead of building and mounting a separate piece for the take-up spool, two rubber washers were creatively used to retain the take-up fishing line from wandering along the length of the shaft. At each end of the shaft are ball bearings which support the continuous rotation of the shaft. These ball bearings are mounted in the walls of a mounting box. Two round nuts are threaded onto each end of the shaft to ensure no slipping of the shaft horizontally.

The mounting box is 8 x 8 x 0.25 inch plexiglass. It has four side walls but no top nor bottom. The top has been eliminated so that the take-up fishing line will have easy access into the turbine. The bottom is eliminated for certain elimination of the used water. During operation this box is screwed onto a 15 x 20 x 0.5 inch mounting board.

A 0.125 inch diameter sweeper nozzle is incorporated into the design. However, to allow for thorough testing, several nozzle types and sizes can be easily threaded onto the inlet tubing of the turbine.

According to the contest rules the inlet to the water turbine must be along the centerline of the runner. The optimum location, however, for the water to impart onto the turbine cups is at mid-center of the lowest cup. In order to compensate for this, a female garden-hose pigtail is used along with wall mounted hose clamps to direct the inlet to this optimum location.

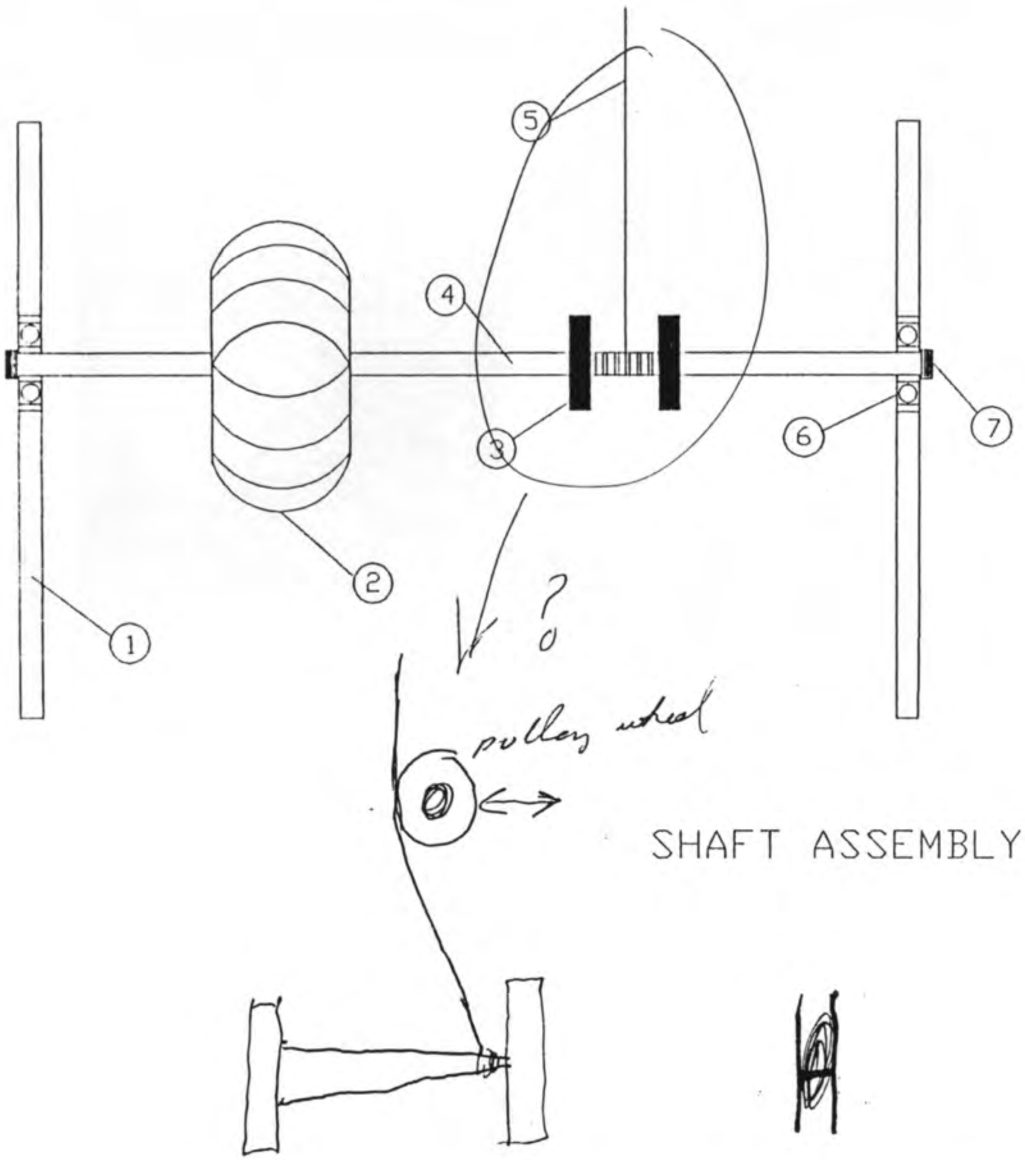
PRELIMINARY DESIGN
Unrestricted Class Entry



1. 0.125 in. nozzle
2. Wall-mount hose fastner
3. 0.5 in. ID polyethylene tubing
4. Female Garden Hose Pigtail

MOUNTING BOX

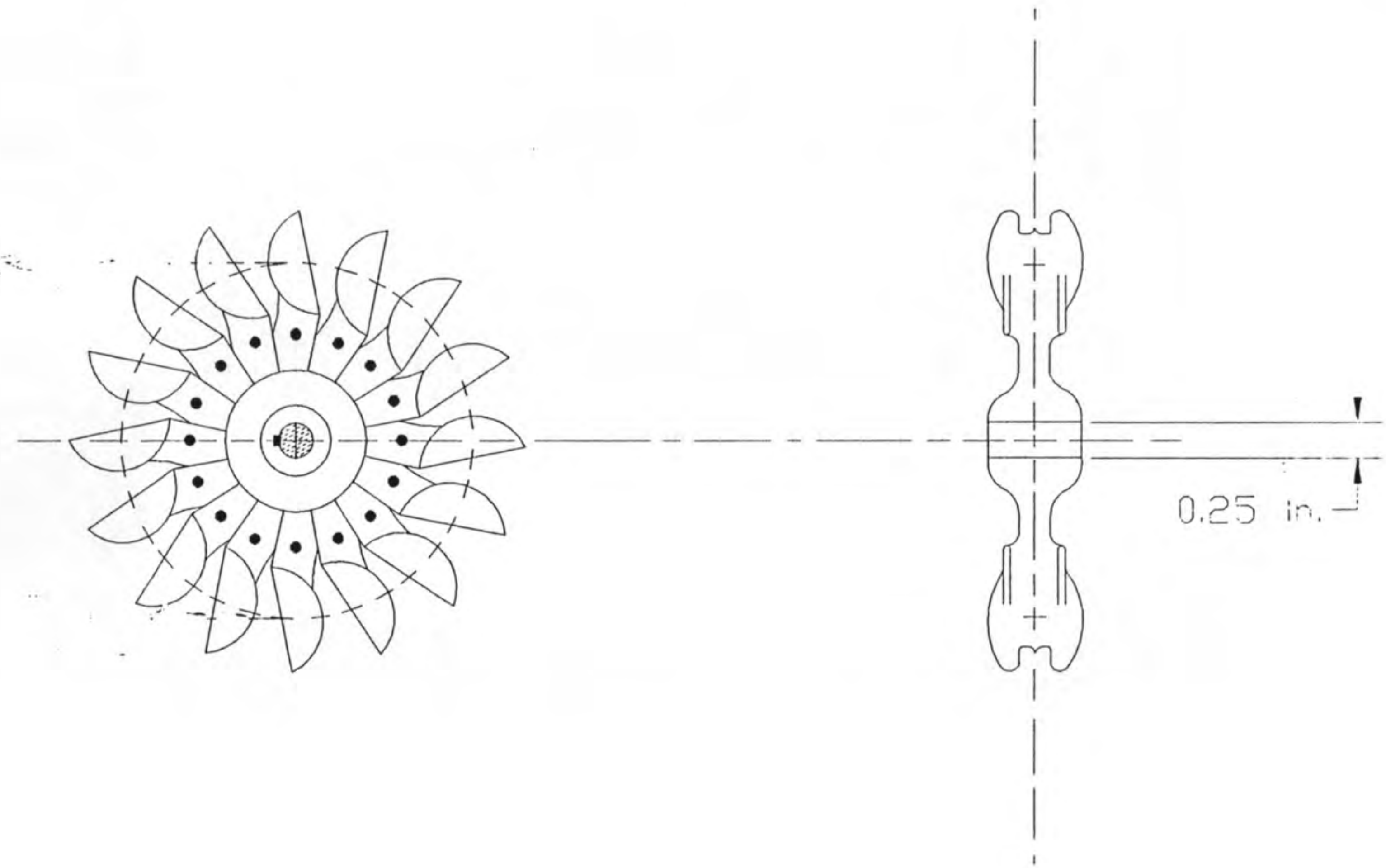
PRELIMINARY DESIGN
Unrestricted Class Entry



SHAFT ASSEMBLY

1. Mounting Box
2. Pelton Wheel
3. Rubber Washers
6. Ball Bearings
4. Shaft
5. Take-Up Line for Weight
7. Round Nut threaded onto each end of Shaft

PRELIMINARY DESIGN
Unrestricted Class Entry



WHEEL TYPE: PELTON WHEEL

FUTURE:

FEASIBILITY OF ANALYTICAL MODEL:

As described earlier in the report several physical tests have been preformed. The purpose of the tests were to gain engineering insight on how to select the design parameters. The information gained has been beneficial in understanding how varying the parameters effect the performance. However, it was not possible to vary all the parameters during the physical tests. For example it was not practical to vary the turbine radius. Because of this limitation attempts were made to model the system analytically.

At this time the analytical model has not been competed. Because of time constraints we are allowing one week to continue working on the analytical model. At the end of that week a decision will be made to finish the model or to channel our efforts to build a physical model to tests this parameter.

FINAL TESTING:

During this analytical process several questions have come up on how to model the system. At this point we are assuming the system will approximate a steady state system. An iterative process using specific speed will be used to select a turbine radius. If attempts are not successful physical tests will be preformed to determine this parameter.

MODIFICATIONS:

Because of the uncertainty of the physical tests and analytical model flexibility of our design becomes important. For example we have a good ideal of the nozzle size but having the ability to easily change the nozzle size has great benefits. This flexibility will take care of any inaccuracy of our tests and also take care of any variations from our test stand and the actual contest stand.

COMPLETE PROJECT:

After the preliminary presentation is given our first goal will be to finalize our design parameters. Attention will need to be given to time constants for this phase of the project. The final phase of the project will be to develop final design drawings and build the device.

HYDROPOWER GROUP

FINAL DESIGN REPORT

TEAM MEMBERS:

STEVE HUNGATE
SUSAN GARRETT
BRIAN COUNCIL
CLAUD MONROE

HYDRO-POWER DESIGN GROUP
224 Wells Fargo Drive
Knoxville, TN 37922
April 22, 1993

Dr. J.R. Parsons,
Professor of Mechanical Engineering
410 Dougherty Engineering Building
The University of Tennessee - Knoxville
Knoxville, TN 37966

Subject: ME-479 HYDRO POWER DESIGN PROJECT - FINAL REPORT

Dear Dr. Parsons:

The purpose for this letter is to transmit the final design report covering the hydro-power design project. The two turbine entries are receiving final adjustments and will be turned over to you following the presentation which is scheduled for April 27, 1993.

The members of this design team wish to thank you for your assistance and patience in bringing this project to completion. We hope that you are pleased with our efforts. This has been a good learning experience. We have made use of our engineering knowledge in areas including fluid mechanics, dynamics and machine design, as well as gained valuable experience in working together as a project team.

As of this date Susan Garrett is the only team member committed to attend WATERPOWER '93, however, others will join if possible.

Sincerely,

HYDRO POWER DESIGN GROUP: Brian Council ____________________

Susan Garrett ____________________

Claud Monroe ____________________

Steve Hungate ____________________

enclosure: Final Design Report

SUMMARY

The second North American Hydro Power Contest under the direction of Hydro Review Magazine and the Tennessee Valley Authority Engineering Laboratory will be conducted as part of WATERPOWER '93 - a hydropower industry conference - in Nashville, Tennessee, August 10-13, 1993. This contest and its rules (see appendix of the final design report) provide the background and basis for the work performed by the UT Mechanical Engineering Hydro Power Design Group (HPDG).

The task is to construct a turbine device within the guidelines which will convert the gravity potential of water into mechanical power. There are several categories for competition among contestants, two of which the HPDG has prepared entries. The categories which HPDG will compete in are; Student Division, Undergraduate Class, referred to as the restricted class entry in the design report, and the Open Division, Unrestricted Class, which has been referred to as the unrestricted class entry in the design report.

The objective is to raise a weight (1 kilogram) a distance of 3 meters with the water supplied through a 1/2-inch I.D. plastic tube from a 4 meter head tank containing 30 liters of water. The device which raises the weight in the least amount of time will be declared the winner.

The HPDG restricted class entry utilizes a 3-inch diameter turbine wheel and gear drive system which was supplied in the contest kit. The results of testing indicate this entry will lift the weight in 36 seconds.

The HPDG unrestricted class entry utilizes a Pelton Wheel which was designed and fabricated by team members and employs a direct drive system. The results of testing for this device indicate it will lift the weight in approximately 15 seconds.

This project has provided the students with an opportunity to work as a group and to utilize their knowledge of fluid mechanics, dynamics and machine design.

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INTRODUCTION:

This final design report documents the work performed by the UT Mechanical Engineering Hydro Power Design Group (HPDG) for the Spring semester 1993, in accordance with course ME-479. This report includes a description of two entries, restricted class and unrestricted class, prepared to compete in the "Hydro Power Contest" during HYDROPOWER '93. HYDROPOWER '93 is the name of the hydropower industry conference which will be held in Nashville, Tennessee, August 10-13, 1993.

The objective of the contest is to raise a weight (1 kilogram) a distance of 3 meters with the water supplied through a 1/2-inch I.D. plastic tube from a 4 meter head tank containing 30 liters of water. The device which raises the weight in the least amount of time will be declared the winner.

This report contains descriptions and outline drawings of the design for both entries. Recommendations which could be employed to improve the lift time are also included, as are calculations, pictures, and a copy of the contest rules.

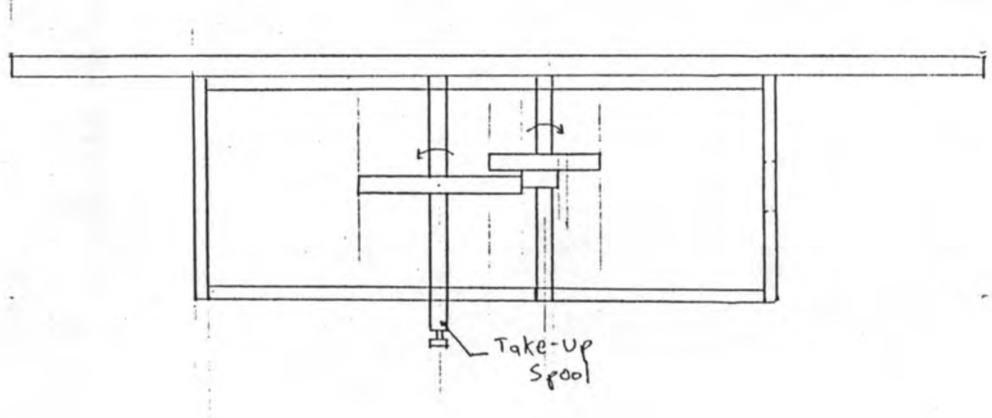
DESIGN:

RESTRICTED CLASS:

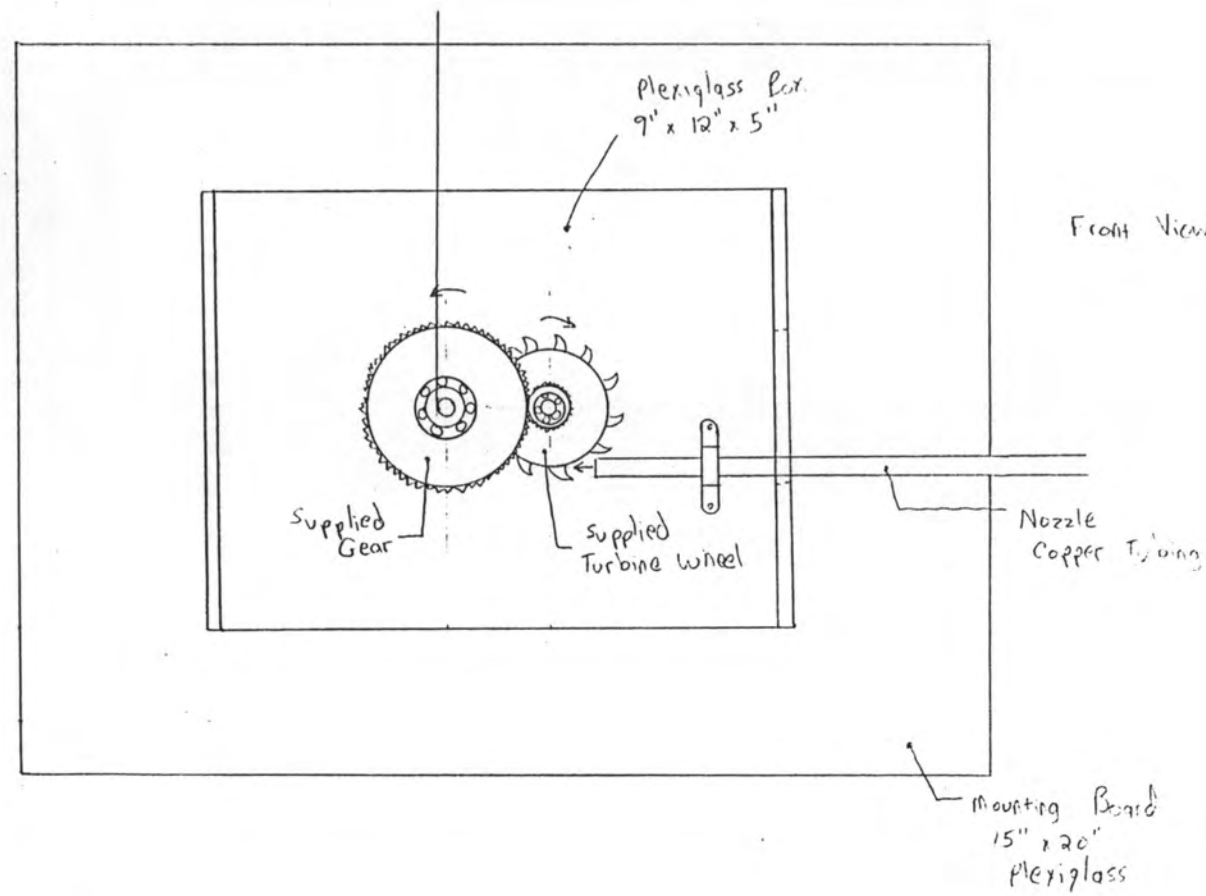
The biggest challenge faced was probably the restricted class entry. The reason for this is simple: the turbine wheel supplied in the contest kit was unimpressive, to say the least. A properly designed Pelton wheel, shown by calculations, would be many times more efficient. However, since using this wheel was a requirement for the Student Division, Undergraduate Class, several good ideas on how to raise the 1 kg weight were put forth.

The initial tests using a head of 4 m, showed that a direct drive system (the first choice for power transmission) would not lift anywhere near the required 1 kg weight. The wheel supplied simply is not a good enough design to do this without some type of gear reduction, even with a very small take-up spool. This was detailed in the preliminary design report.

It was decided to use the wheel with the supplied gear to reduce the amount of torque needed to lift the weight. The mounting board for this set-up is very similar to the original scheme, except there are two shafts instead of one. A sketch of this power transmission system is given later in the report. This new gear reduction system has proven through testing that it can lift the required 1 kg weight. The fastest time to date is approximately 36 seconds, and there is still room for improvement in these last two weeks of classes. For example, plans include ultrasonically cleaning the bearings to reduce friction. Also, since the gear supplied is not very accurate, there is some gear teeth clash. Some lubricant placed on the gear would definitely decrease the lift time.



Top View
(Nozzle Excluded)



Front View

UNRESTRICTED CLASS:

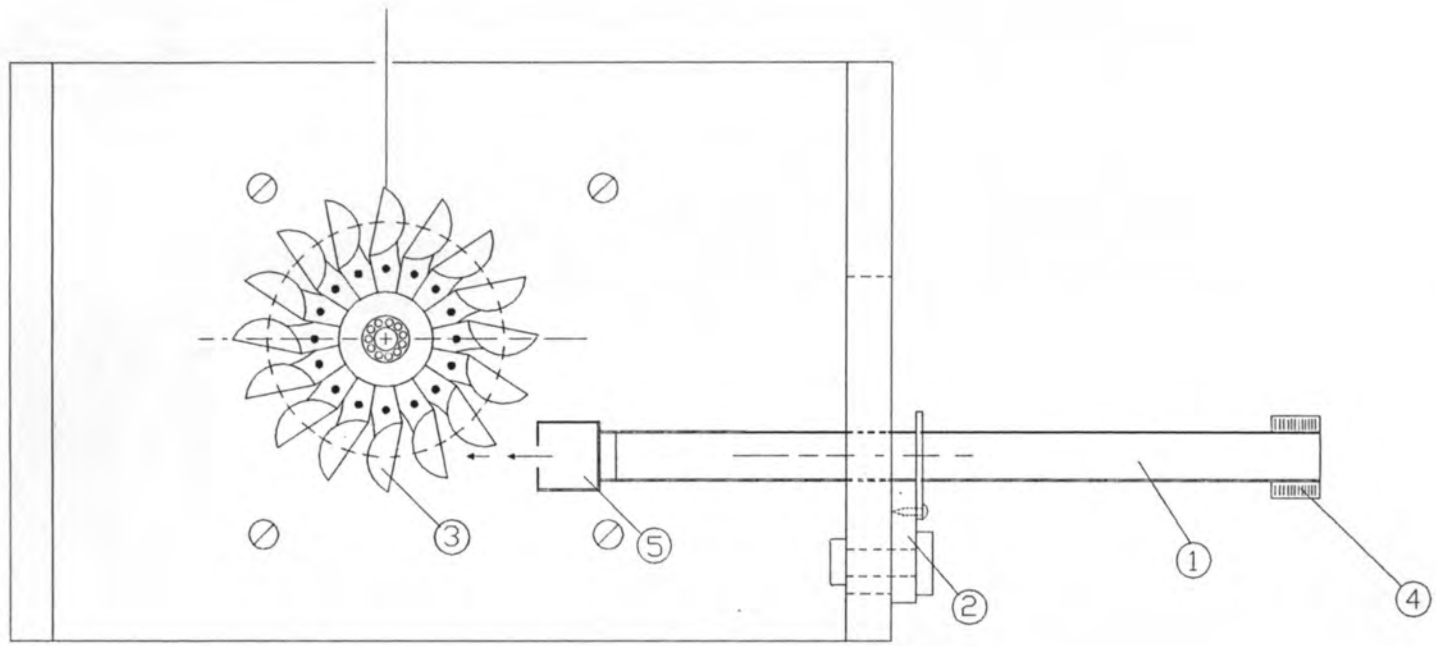
The final design for the unrestricted class entry utilizes a Pelton wheel. The Pelton wheel has a runner radius of 2.5 inches with its cups fabricated from Alumilite Casting Plastic. The cups are secured to the hub with 0.125 inch OD screws through the cups and the hub. The wheel is mounted onto a 0.375-inch OD stainless steel shaft. To support testing, two additional Pelton wheels were built which can be easily interchanged onto the shaft. The second wheel has a radius of 1.75 inches and the third has a radius of 3.0 inches.

In order to incorporate a take-up spool into the design we have found that a reduction in spool diameter provides maximum benefit. A section of the shaft was machined to 0.25-inch diameter to accomplish this purpose. At each end of the shaft are ball bearings which support the continuous rotation of the shaft. These ball bearings are mounted in the walls of the mounting box. Two nuts are threaded onto each end of the shaft to ensure no translation of the shaft horizontally.

The polycarbonate mounting box is 8 x 8 x 0.25-inches. It has four side walls but no top or bottom. The top has been left open to allow attachment of the fishing line to the take-up spool. The bottom is open for drainage of the water. This box is mounted onto a 15 x 20 x 0.5-inch mounting board.

FINAL DESIGN

UNRESTRICTED CLASS ENTRY



1. 0.5 in. ID Thin Walled Copper Tubing
2. Nozzle Support
3. Pelton Wheel (5.0 in. Runner Dia.)
4. Female Garden Hose Connector
5. 0.25 in. Nozzle

RESULTS:

During the final design phase of the project both the open and restricted class entries were tested. Several design parameters of each entry were evaluated. The purpose for the tests was to fine tune the performance of each turbine.

Two different types of nozzle designs were tested. The designs were a sweeper nozzle and an orifice type nozzle. The sweeper nozzle can be described as a long tapered nozzle with a opening of 0.1875 inches. The sweeper nozzle proved to be ineffective as compared to the performance of the orifice and was discarded. The orifice nozzles were made by drilling holes of varies sizes in the end of copper pipe caps. In an effort to achieve a uniform jet through the orifice, the hole was bored to give a slight taper in the opening. As shown in the following tables, the best performance was obtained with the .25 inch nozzle size.

RESTRICTED CLASS	1/8" TAKE-UP SPOOL
NOZZLE SIZE (in)	LIFT TIME (sec)
.1875	38.6
.25	36.2
.3125	44.7

OPEN CLASS (3" RADIUS)	1/4" TAKE-UP SPOOL
NOZZLE SIZE (in)	LIFT TIME (sec)
.1875	23.3
.25	16.6
.3125	18.6

The 4-inch size turbine was tested using only the 0.25-inch diameter orifice since, as the above tables indicate, it was shown to be the best design.

OPEN CLASS (2.5" RADIUS)	1/4" TAKE-UP SPOOL
NOZZLE SIZE (in)	LIFT TIME
.25	15.2

Besides the nozzle the only other design parameter that was varied on the restricted class entry was the take-up spool size. Two different diameters were tested, .25 and .125 inches. The resisting torque proved to be too great when the .25-inch take-up spool was used and the system stalled. The 0.125-inch spool provided the best result which was an average lift time of 36.2 seconds.

For the open class entry two design parameters were evaluated, turbine radius and take-up spool diameter. The three turbine radii tested were 1.75, 2.5, and 3 inches. The 2.5-inch radius was found to produce the fastest lift time. The two take up spool sizes tested were .375 and .25 inches. The .25-inch diameter was found to give the best results.

It is fair to mention several problems encountered during the tests. First, the lubrication was washed out of the bearings on the restricted class entry, resulting in unacceptably high friction. Undue friction was also caused by clash in the nylon gears. This could be eliminated by lubrication or replacing the gears with a precision ground set of metal gears.

The shaft for the open class entry had a tendency to move laterally due to the retaining nuts backing off, allowing the turbine to move away from the water stream. Also, the width of the take up spool was too narrow. This allowed the fishing line to travel from the take-up spool and begin winding onto the shaft causing higher resisting torque, resulting in longer lift times. The last problem encountered for the open class entry was the alignment of the 3 inch radius turbine wheel. Due to imbalance in that wheel, the water jet hit the cups in an inconsistent pattern, which affected its power.

CONCLUSIONS/RECOMMENDATIONS:

As mentioned in the results section, the orifice nozzle with a .25 inch hole performed the best. Preliminary calculations had indicated that the sweeper nozzle with a .1875 inch opening would perform the best. Subsequent calculations indicated that the orifice is in fact the best design due to its larger Cv. Also, the orifice nozzle gave the best combination of water mass flow rate and jet velocity.

The best open class turbine radius was predicted by calculations to be 2.5 inches. This was confirmed by testing. This can be explained by the fact that the 2.5 inch runner radius wheel operated at a higher specific speed.

Several recommendations can be made to solve the problems encountered during the test runs. The bearings on the restricted class turbine need to be shielded from the water spray to prevent the lubrication from being washed away. Also, lubrication of the gears with a lubricant such as graphite would reduce friction in the gears.

Another recommendation is to increase the width of the take up spool on the open class turbine to eliminate the problem of the fishing line traveling off of the spool. The most irritating problem encountered was the lateral movement of the shaft, which can be corrected by using friction nuts. It is highly recommended that these problems be corrected before the contest.

APPENDICES

APPENDIX A 1/19/93

HYDRO POWER CONTEST

$20,000 Cash, Scholarships & Prizes!

DO YOU HAVE A WINNING IDEA FOR TURNING WATER INTO POWER?

If so, it's time to enter the second HYDRO POWER CONTEST.

This information kit provides a description of the contest, an outline of the contest rules and parameters, and information on how to enter.

Sponsored By:

- Acres International Corporation
- Alabama Power Company
- American Hydro Corporation
- Black & Veatch
- British Columbia Hydro
- Bureau of Reclamation
- California Department of Water Resources
- Canadian Electrical Association
- Consolidated Hydro, Inc.
- Edison Electric Institute
- Electric Power Research Institute
- The Harza Companies
- Hewlett-Packard Co.
- Hydro Review Magazine
- Hydro West Group, Inc.
- IMPSA International, Inc.
- Kvaerner Hydro Power, Inc.
- Lafarge Calcium Aluminates
- National Hydropower Association
- Neyrpic, Inc.
- Noell, Inc.
- Pacific Gas and Electric Company
- Parsons Main, Inc.
- Siemens Power Corporation
- Sulzer Escher Wyss Hydro, Division of Sulzer Canada Inc.
- Swirlon International
- Synergics, Inc.
- Tennessee Valley Authority
- Thordon Bearings Inc.
- U.S. Department of Energy
- Vibro-Meter, Inc.
- Voith Hydro, Inc.
- The Washington Water Power Company
- WATERPOWER '93 Conference
- Weld Mart, Inc.
- Woodward Governor Company

Contest Description

Several industry organizations, with leadership from *Hydro Review* magazine and the Tennessee Valley Authority Engineering Laboratory, have organized the second North American Hydro Power Contest for university and college students and other interested individuals. The competition will take place during WATERPOWER '93 — a hydropower industry conference held every other year — in Nashville, Tennessee, August 10-13, 1993.

To participate in the competition, each contestant is required to construct a device that converts the gravity potential of water into mechanical power. During WATERPOWER '93, contestants' devices will be tested. In the test, the mechanical power produced will be measured by the time, in seconds, it takes to lift a weight a fixed distance. The design that lifts the weight in the shortest period of time wins the contest. This year's contest also will include an efficiency competition, which permits contestants to submit entries seeking a different objective than the "mainstream" contest. In this division, contestants' devices are to lift the weight using the minimum amount of water within a maximum time constraint of 2 minutes. A panel of industry experts will serve as contest monitors and judges.

Contestants' designs must incorporate a turbine wheel, which will be provided to contest applicants. The device may use shafts, gears, pulleys, or other mechanisms attached to the mounting board to convert the turbine power into mechanical power to lift the weight.

The contest is comprised of four divisions: student division, open division, "pro" division, and efficiency division. The first two — student and open — each have two classes:

Student Division

Undergraduate Class (for regularly enrolled full-time undergraduate students at colleges and universities; this includes high school students graduating in the spring of 1993 and enrolled in a college or university for the fall of 1993)

Graduate Class (for regularly enrolled full-time graduate students at colleges and universities; this includes undergraduate students graduating in the spring of 1993 and enrolled in a graduate program at a college or university for the fall of 1993)

Open Division

General Class (for all entrants not eligible for any of the classes in the student division)

Unrestricted Class (for any entrant—students and others) In this class, entrants aren't required to use the supplied turbine wheel. However, the motive force for lifting the weight must be developed using a water-powered turbine-type device.

The "Pro" and Efficiency Divisions are new additions to the 1993 Hydro Power Contest:

"Pro" Division

This new division is only open to prior winners (1st, 2nd, and 3rd place winners) of either the Student or Open Division awards. To enter this division, contestants' devices must be of the "unrestricted" variety. The same rules for the Open Division, Unrestricted Class apply. Prior winners are not allowed to participate in the same class(es) as in 1991.

Efficiency Division

The objective of the competition is to lift the weight using the minimum amount of water within a maximum time constraint of 2 minutes. To enter this division, contestants' devices must be of the "restricted" variety — they must use the provided turbine wheel. This division is open to any contestant.

Prizes

More than $20,000 in scholarships, cash, and prizes will be awarded to participants in the 1993 Hydro Power Contest. Prizes for first place winners include:

Student Division
(both Undergraduate and Graduate Classes)

- Scholarship Awards: top winners will receive substantial scholarship awards from the U.S. Department of Energy and others
- $1,000 Cash
- Hewlett-Packard HP 48SX scientific calculator

Open, Pro, and Efficiency Divisions

- $1,000 Cash
- Hewlett-Packard HP 48SX scientific calculator

Additional prizes will be awarded to 2nd and 3rd place winners in each division. Winners will be publicized in *Hydro Review*. All competitors will receive a free one-year subscription to *Hydro Review*.

How to Enter

To enter, contestants should send an entry fee of $15, payable to Hydro Power Contest, along with their name, address, and daytime telephone number, to: Hydro Power Contest, c/o *Hydro Review*, 410 Archibald Street, Kansas City, MO 64111.

Entries can be from either individuals or teams. An entry may be entered in any class in any division for which it is eligible, but may compete in only one class. For each division entered, the contestant must construct a new device. A contestant can enter a maximum of two devices. Entries will be accepted until May 15, 1993.

Entrants will receive a contest kit: a turbine assembly, an extra turbine wheel, a copy of the contest rules (this information kit), and a complimentary copy of *Hydro Review*.

For more information about the contest, contact *Hydro Review* at (816) 931-1311; FAX: (816) 931-2015.

Technical Advisory Committee

Members of the contest's technical advisory committee developed the contest parameters, and will serve as technical advisers for the contest.

Committee members are:

— Michael Coates, senior engineer, New England Power Service Company and former contest participant

— John Gulliver, PhD, professor and researcher, St. Anthony Falls Hydraulic Laboratory, University of Minnesota

— Patrick March, senior mechanical engineer at the TVA Engineering Laboratory, Tennessee Valley Authority

— Lee Sheldon, senior hydropower specialist, Bonneville Power Administration

Contest Rules & Parameters

1) Each entrant must construct a mechanical mechanism to convert water power into mechanical movement. During the competition in the Student, Open, and Pro Divisions, each contestant's water turbine-powered device will be tested to see which entry can succeed in most quickly lifting a fixed weight (1 kilogram) a specified vertical distance (3 meters). In the Efficiency Division, each contestant's water turbine-powered device will be tested to see which entry can lift a fixed weight (1 kilogram) a specified vertical distance (3 meters) with the least amount of water.

2) The measure of mechanical power produced will be the time, in seconds, required for the contestant's device to lift the weight to the 3-meter vertical height. The number of seconds required to lift the weight will be the contestant's score. The entry in each division and/or class in the Student, Open, and Pro Divisions with the lowest score will win the contest. For the Efficiency Division, time and flow rate will be continuously monitored and integrated to give the volume of water used to lift the weight. The entry that uses the least amount of water will win the contest.

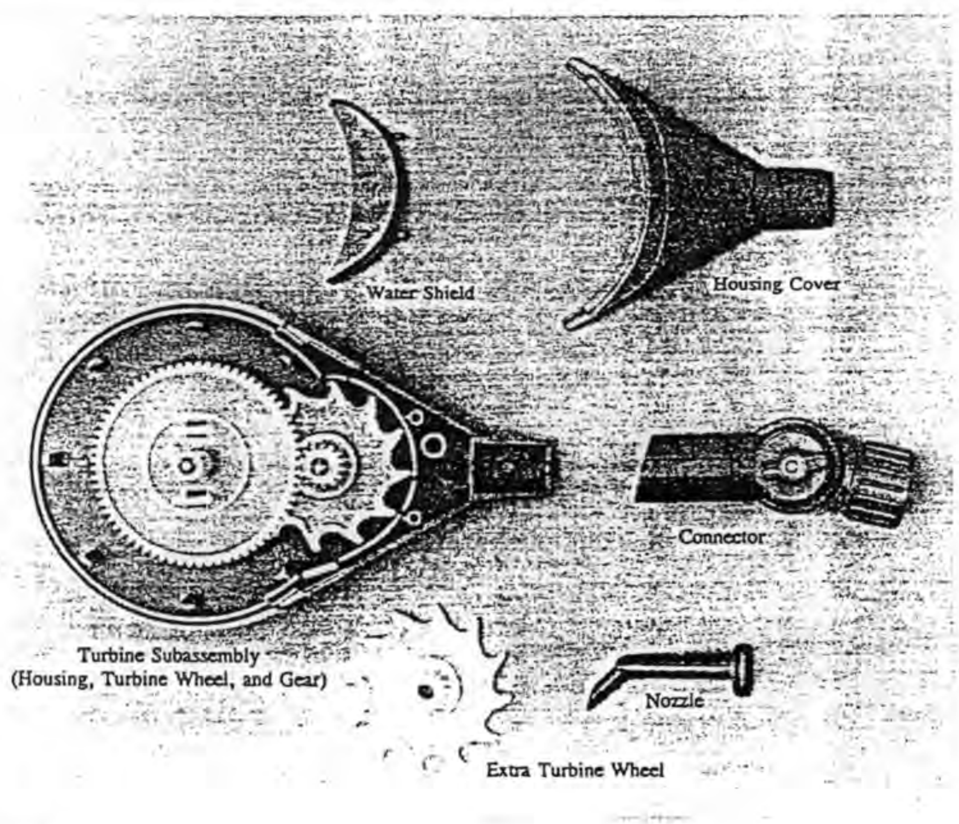


Figure 1

3) Each entrant in the contest will be supplied with a water turbine assembly and one extra turbine wheel. Any and all parts of this assembly can be used by the entrant. (See Figure 1 for turbine components.) However, as a minimum, the turbine wheel must be used, and only one turbine wheel may be used for each entry. No such limitations apply in the unrestricted class of the Open Division or in the Pro Division.

4) No modification of the turbine wheel supplied is allowed other than cleaning up the wheel to remove molding marks and flashing. All other parts of the turbine assembly may be eliminated or extensively modified. Contestants are not restricted to using the supplied gears and bearings.

5) In the Unrestricted Class and Pro Division competitions, the requirement to use the supplied turbine wheel is waived. However, some type of turbine device must be used for converting the water power to mechanical power.

6) All motive force produced by the contestant's device for lifting the weight must come from the potential and kinetic energy of the water that flows through the device.

7) No electrical or electronic items may be part of a contestant's device.

8) During the competition event at the WATERPOWER '93 conference, a representative of each entry must be present to set up the device that is entered for testing. If an entrant cannot arrange for a representative to be present, *Hydro Review* will, upon request, seek to arrange for representation.

9) Each entry representative will be allowed a maximum time of 15 minutes. This includes setting up the device for testing, making trial runs and doing adjustments, completing a maximum of two competition runs, and disassembly. Contestants cannot touch the device during competition runs. Contestants must advise the contest judges regarding which runs are competition runs before the runs begin.

10) In the test, up to 30 liters of water will be allowed to flow from a 4-meter elevation through a conduit (a 1/2-inch inside diameter polyethylene tube). The water will pass through the contestant's device. The device, in turn, will lift a 1 kilogram weight vertically 3 meters. A sump beneath the testing apparatus will collect water flowing out of the device. Figure 2 is a scale drawing of the testing apparatus with various instructions.

11) The contestant's assembly shall be on a mounting board that is 51

centimeters (20 inches) wide and 38 centimeters (15 inches) in height. The mounting board shall be 1/2 inch thick.

12) The mounting board will be affixed to the mounting rails on the testing apparatus with clamps, furnished at the test location. The centerline of the contestant's runner will be placed at a fixed elevation on the test stand. When mounted on the test stand, no part of the contestant's device — with the exception of the take-up line — may extend beyond the edges of the mounting board. Figure 2 illustrates where the mounting board fits on the testing apparatus.

13) When mounted for testing, the turbine shaft can be in any configuration. The centerline of the runner in any configuration (vertical or horizontal) shall be equal to the elevation of the centerline of the inlet valve.

14) No means of storing mechanical energy in the device or take-up line prior to its operation by water will be allowed.

15) When mounted, the contestant's turbine will be connected to the test apparatus with a garden hose-type pigtail (for supplying water to the contestant's device) and through a fish line connector (to connect the contestant's cord to the fish line that is attached to the 1 kilogram weight). The pigtail and fish line connector will be furnished at the test location.

16) For the test, each contestant must supply the turbine and a motion translator (take-up) device, including a fish line (or similar cord) for connection to the weight lifting line. The connector line must be at least a 17 pound test fishing line (monofilament or equivalent) and be 4 meters long. (See Figure 2). The fish line take-up should be perpendicular to the mounting board for best performance.

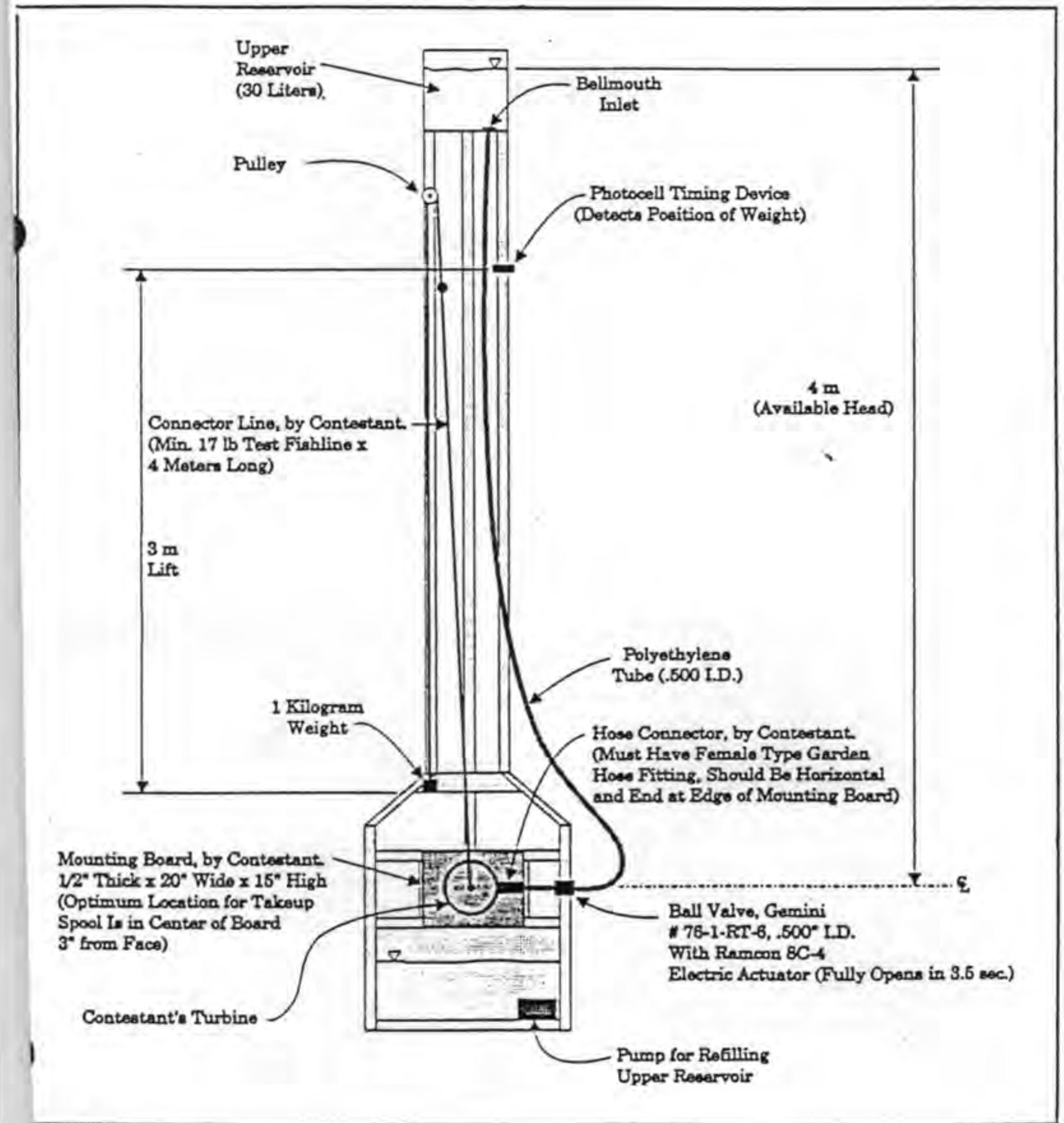
17) The contestant's device shall include a standard garden hose type female connector (mounted horizontally) for connection to the water supply on the testing apparatus. (See Figure 2).

18) Prior winners of the Hydro Power Contest are not allowed to participate in the class(es) that they entered in 1991.

19) At the option of contest judges, devices are subject to impoundment for examination prior to being returned to contestants. In the event of a dispute, the opinion of the judges is final.

20) Devices shall remain at the contest booth for display after the contest runs until the conclusion of WATERPOWER '93, at which time the devices will be retrieved by the contestants.

21) The foregoing rules are subject to change at any time.



igure 2

Notice: The turbine device supplied to contestants for use in this contest was manufactured by Swirlon International and is protected by certain patents. The use of the Swirlon device by contest participants for contest purposes does not convey to participants any license or rights to Swirlon's registered and pending patents.

For additional copies of this information kit, contact:

Hydro Power Contest
c/o *Hydro Review*
410 Archibald Street
Kansas City, MO 64111
PHONE (816) 931-1311
FAX: (816) 931-2015

APPENDIX B

```
ME-479 DESIGN PROJECT FINAL CALC.   fn (479FINAL)
========================================================================
The lift times reflected in this final version of the calculation
are those actually measured during the tests.


The following section is for the open class wheel:
========================================================================
  Force Wt. =  2.2053 lbf
  Lift Time =      15 seconds<<< MEASURED
Spool Radius = 0.1875 inches <<< ACTUALLY 0.125, LARGER VALUE REFLECTS
Turbine Rad. =    2.5 inches     LINE BUILD-UP ON THE SPOOL.
    Lift =     118.11 inches
  Lift Vel. =   7.874 in/sec
    Omega =    41.994 rad/sec
     RPM =     401.01
      U =      8.7488 ft/sec
specific wt. =   62.3 lbf/ft^3
   density   =  1.936 slugs/ft^3
     Beta    =    170 degrees
     Beta    = 2.9670 radians
 Nozzle Dia. =   0.25 inches
 Area Nozzle = 0.0003 ft^2
     Cv      =   0.98
     Q       =   2.91 GPM    <<< MEASURED
     Q       = 0.0064 ft^3/sec
     Vj      = 19.018 ft/sec
   head      = 5.8483 ft     <<< CALCULATED AT NOZZLE INLET
   press     = 2.5318 PSI    <<< CALCULATED AT NOZZLE INLET

   FORCE     = 0.2558 LB     <<< FORCE ACTING ON THE VANE
   TORQUE    = 0.2261 in-lb  <<< NET TORQUE ACTING ON THE WHEEL
   bhp       = 0.0014
   Nsp       = 1.6725
   PHI       = 0.4508 velocity factor
   Efficiency= 94.700 percent
```

```
The following section is for the restricted class wheel:
=======================================================================
  Force Wt. =  2.2053 lbf
  Lift Time =      36 seconds<<< MEASURED
Spool Radius =  0.125 inches <<< ACTUALLY 0.0625, LARGER VALUE REFLECTS
Turbine Rad. =   1.25 inches      LINE BUILD-UP ON THE SPOOL.
    Lift =     118.11 inches
  Lift Vel. =  3.2808 in/sec
  Omega (1) =  26.246 rad/sec, Omega (1) is angular velocity of gear
 Gear Ratio =     4.6 :1
  Omega (2) =  120.73 rad/sec, Omega (2) is angular velocity of turbine
     RPM =     1152.9
  Rad. Gear =    1.75 inches
 Rad. Pinion = 0.3804 inches
 Gear Force =  0.1575 lb
      U =      12.576 ft/sec
specific wt. =   62.3 lbf/ft^3
   density   =  1.936 slugs/ft^3
     Beta    =     90 degrees
     Beta    = 1.5707 radians
 Nozzle Dia. =   0.25 inches
 Area Nozzle = 0.0003 ft^2
     Cv      =   0.98
     Q       =   2.91 GPM    <<< MEASURED
     Q       = 0.0064 ft^3/sec
     Vj      = 19.018 ft/sec
   head      = 5.8483 ft     <<< CALCULATED AT NOZZLE INLET
   press     = 2.5318 PSI    <<< CALCULATED AT NOZZLE INLET

   FORCE     = 0.0808 LB     <<< FORCE ACTING ON THE VANE
   TORQUE    = 0.0411 in-lb  <<< NET TORQUE ACTING ON THE WHEEL
   bhp       = 0.0007
   Nsp       = 3.4782
   PHI       = 0.6480 velocity factor
   Efficiency= 43.024 percent
```

PURPOSE: TO VERIFY ADQUACY OF SPREADSHEET

ASSUMPTIONS: See Pg 6 of 6

REFERENCES: See Pg 6 of 6

GIVEN:

Nozzle: 1/4" ϕ ORIFICE ⇐ Optimum Size determined Thru testing
C_v = 0.98 (Ref. 1)

FLOW RATE: Q = 2.91 GPM ⇐ Measured with 1/4" ϕ Nozzle Attached

Weight: $(1\ Kg)(9.81\ m/s^2)\left(\frac{0.22481\ lbf}{N}\right) \Rightarrow \underline{\underline{Wt. = 2.2053\ lbf}}$

Lift: $3\ m\left(\frac{39.37\ in}{m}\right) \Rightarrow \underline{\underline{Lift: 118.11\ in}}$

WATER: Specific Wt. = 62.3 lbf/ft^3, density = 1.936 $slugs/ft^3$ (Ref. 2)

Restricted Turbine:

Diameter = 2.5 IN ⇐ measured

Pinion: Number of Teeth = 15
Radius = 0.3804 inches

Gear: Number of Teeth = 69
Radius = 1.75 inches

Gear Ratio: 69/15 = 4.6 : 1

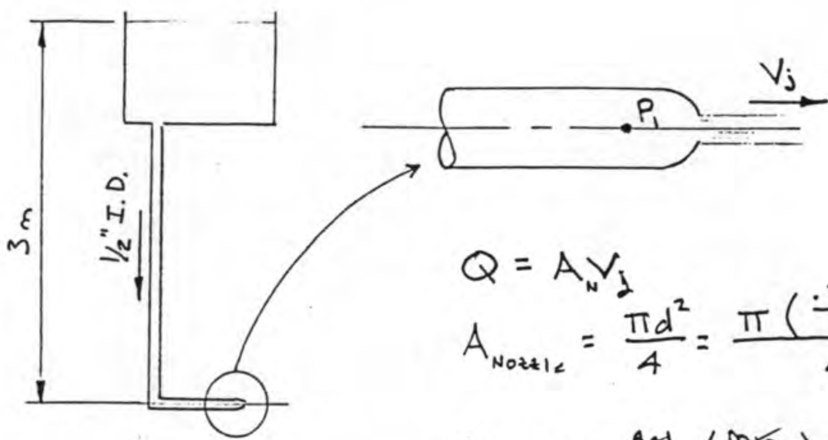
$\beta = 90°$ ⇐ estimated

Unrestricted Turbine:

Diameter = 5 inches ⇐ measured

$\beta = 170°$ ⇐ estimated

ANALYSIS:



$$Q = A_N V_j$$

$$A_{Nozzle} = \frac{\pi d^2}{4} = \frac{\pi \left(\frac{.25}{12}\right)^2 ft^2}{4} \Rightarrow \underline{\underline{A_N = 3.409E\text{-}4\ ft^2}}$$

$$Q = 2.91\ \frac{gal}{\cancel{min}}\left(\frac{\cancel{min}}{60\ sec}\right)\left(\frac{35.313\ ft^3}{264.17\ \cancel{gal}}\right) \Rightarrow \underline{\underline{Q = 6.483E\text{-}3\ \frac{ft^3}{sec}}}$$

$$V_j = \frac{Q}{A_N} = \frac{6.483E\text{-}3\ ft^3/sec}{3.409E\text{-}4\ \cancel{ft^2}} \Rightarrow \underline{\underline{V_j = 19.02\ ft/sec}}$$

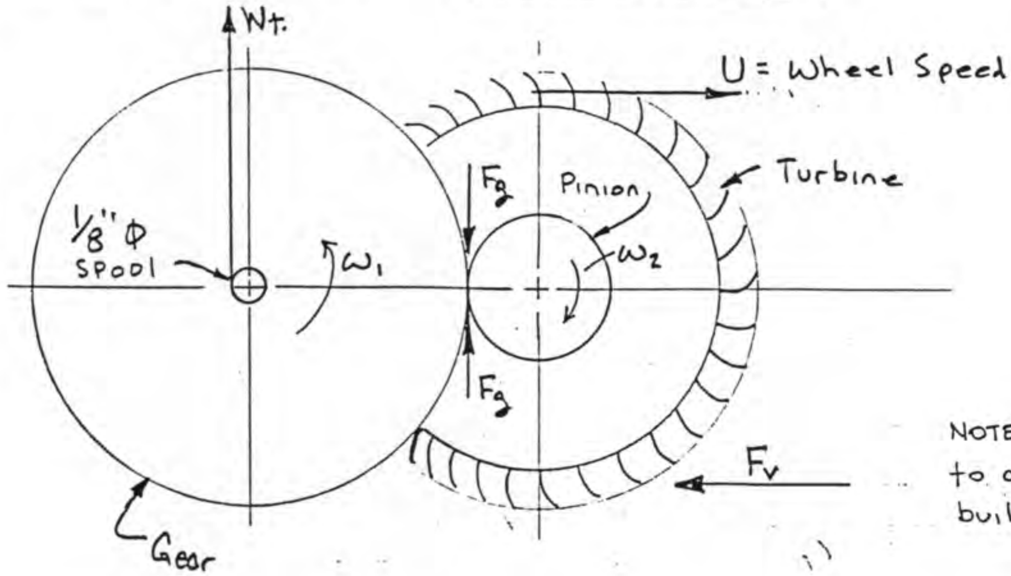
$$V_j = C_v\sqrt{2gh_1} \quad (\text{Ref.}\quad)$$

$$h_1 = \frac{(V_j/C_v)^2}{2g} = \frac{(19.02\ ft/sec\ /\ 0.98)^2}{2\,(32.2\ ft/sec^2)} \Rightarrow \underline{\underline{h_1 = 5.85\ ft}}$$

$$P_1 = \rho g h_1 = \left(1.936\ \frac{\cancel{slugs}}{\cancel{ft^3}}\right)\left(\frac{lb\cdot\cancel{sec^2}}{\cancel{ft}\cdot\cancel{slug}}\right)\left(32.2\ \frac{\cancel{ft}}{\cancel{sec^2}}\right)\left(5.85\ \cancel{ft}\right)\left(\frac{\cancel{ft^2}}{144\ in^2}\right)$$

$$\underline{\underline{P_1 = 2.53\ PSI}}$$

ANALYSIS CONT: Restricted Class



NOTE: Use spool dia. to account for line build-up. (conservative)

$$Wt. \times R_s = F_g \times R_g \Rightarrow F_g = Wt. \left(\frac{R_s}{R_g}\right) = 2.2053 \text{ lbf} \left(\frac{0.125}{1.75}\right)$$

$\underline{F_g = 0.1575 \text{ lbf}}$

Lift Time = 36 sec ⇐ ASSUME

$$\text{Lift Velocity} = \frac{\text{Lift}}{\text{Lift Time}} = \frac{118.11 \text{ IN}}{36 \text{ sec}} = \underline{3.2808 \text{ IN/sec} = V_L}$$

$$V = r\omega \Rightarrow \omega_1 = \frac{V_L}{r_s} = \frac{3.2808 \text{ IN/sec}}{(0.125 \text{ IN})} \Rightarrow \underline{\omega_1 = 26.25 \text{ rad/sec}}$$

$$\frac{\omega_2}{\omega_1} = \frac{N_2}{N_1} \Rightarrow \omega_2 = 26.25 \frac{\text{IN}}{\text{sec}} \left(\frac{69}{15}\right) \Rightarrow \underline{\omega_2 = 120.73 \frac{\text{rad}}{\text{sec}}}$$

$$RPM = \omega_2 \left(\frac{60}{2\pi}\right) = 120.73 \frac{\text{rad}}{\text{sec}} \left(\frac{60 \text{ sec}}{\text{min}}\right)\left(\frac{\text{rev}}{2\pi \text{ rad}}\right) = \underline{1152.9 \text{ RPM}}$$

$$U = r_t \cdot \omega_2 = (1.25 \text{ IN})(120.73 \text{ rad/sec})\left(\frac{\text{ft}}{12 \text{ IN}}\right) \Rightarrow \underline{U = 12.576 \text{ ft/sec}}$$

$$F_V = \rho Q (V_j - U)(1 - \cos\beta)$$

$$F_V = \left(1.936 \frac{\text{slugs}}{\text{ft}^3}\right)\left(\frac{\text{lb} \cdot \text{s}^2}{\text{ft} \cdot \text{slug}}\right)\left(6.483\text{E-3} \frac{\text{ft}^3}{\text{sec}}\right)(19.02 - 12.576)\frac{\text{ft}}{\text{sec}}\left(1 - \cos 90^\circ\right)$$

$\underline{F_V = 0.0808 \text{ lb}}$

ANALYSIS CONT: Restricted Class Cont.

$$\text{Torque} = (F_v \cdot R_T) - (F_g \cdot R_p)$$

$$= (0.0808 \text{ lb})(1.25 \text{ in}) - (0.1575 \text{ lb})(0.3804 \text{ in})$$

$$\underline{\text{Torque} = 0.0411 \text{ in}\cdot\text{lb}}$$

$$bhp = T \cdot \omega_2 = (0.0411 \cancel{\text{in}\cdot\text{lb}})(120.73 \tfrac{\text{rad}}{\text{sec}})\left(\tfrac{\text{ft}}{12 \cancel{\text{in}}}\right)\left(\tfrac{\text{hp}}{550 \cancel{\text{lb}\cdot\text{ft/sec}}}\right)$$

$$\underline{bhp = 0.00075 \text{ hp}}$$

$$N_{sp} = \frac{Rpm \cdot bhp^{1/2}}{h_1^{1.25}} = \frac{(1152.9)(0.00075)^{1/2}}{(5.85)^{1.25}}$$

$$\underline{N_{sp} = 3.47}$$

$$\phi = \frac{U}{\sqrt{2gh_1}} = \frac{12.576 \text{ ft/sec}}{\sqrt{(2)(32.2 \text{ ft/sec}^2)(5.85 \text{ ft})}}$$

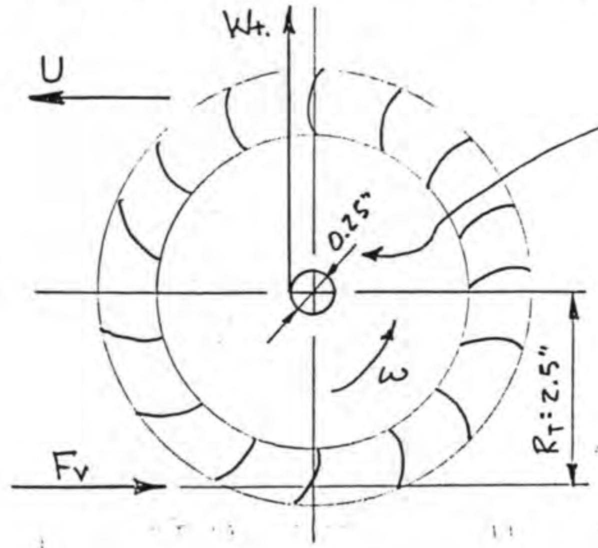
$$\phi = 0.647$$

$$\eta = 2(1 - \cos\beta)\,\phi\,(C_v - \phi) \quad \{\text{Ref. 2}$$

$$\eta = 2(1 - \cos 90°)(0.647)(0.98 - 0.647)$$

$$\underline{\eta = 43\%}$$

ANALYSIS CONT: <u>Unrestricted Class</u>



Assume R_S = 0.1875 IN to allow for line build-up. (Conservative)

Lift Time = 15 sec ⇐ Assumed

Velocity Lift = $\frac{\text{Lift}}{\text{Lift Time}} = \frac{118.11 \text{ IN}}{15 \text{ sec}} \Rightarrow \underline{\underline{V_L = 7.874 \text{ IN/sec}}}$

$\omega = \frac{V_L}{r_s} = \frac{7.874 \text{ IN/sec}}{0.1875 \text{ IN}} = \underline{\underline{41.994 \frac{\text{rad}}{\text{sec}} = \omega}}$

$RPM = \omega\left(\frac{60}{2\pi}\right) \Rightarrow \underline{\underline{RPM = 401}}$

$U = r_t \cdot \omega = (2.5 \text{ in})(41.994 \frac{\text{rad}}{\text{sec}})(\frac{\text{ft}}{12 \text{ in}}) \Rightarrow \underline{\underline{U = 8.7488 \frac{\text{ft}}{\text{sec}}}}$

$F_V = \rho Q (V_j - U)(1 - \cos\beta)$

$F_V = (1.936)(6.483\text{E-}3)(19.02 - 8.7448)(1 - \cos 170°)$

$\underline{\underline{F_V = 0.2558 \text{ lb}}}$

Torque = $(F_V \cdot R_T) - (Wt. \cdot R_S)$

Torque = $(0.2588)(2.5) - (2.2053)(0.1875)$

<u>Torque = 0.2262 IN·lb</u>

ANALYSIS CONT: Unrestricted Class Cont.

$$bhp = T \cdot \omega = (0.2262 \text{ in.lb})\left(41.994 \frac{rad}{sec}\right)\left(\frac{ft}{12 \text{ in}}\right)\left(\frac{hp}{550 \text{ lb} \cdot ft/sec}\right)$$

$$\underline{\underline{bhp = 0.00144 \text{ hp}}}$$

$$N_{sp} = \frac{Rpm \cdot bhp^{1/2}}{h_1^{1.25}} = \frac{(401)(0.00144)^{1/2}}{(5.85)^{1.25}}$$

$$\underline{\underline{N_{sp} = 1.672}}$$

$$\phi = \frac{U}{\sqrt{2gh_1}} = \frac{8.7488 \text{ ft/sec}}{\sqrt{(2)(32.2 \text{ ft/sec}^2)(5.85 \text{ ft})}}$$

$$\underline{\underline{\phi = 0.4507}}$$

$$\eta = 2(1-\cos\beta)\,\phi\,(C_v - \phi)$$

$$\eta = 2(1-\cos 170^\circ)(0.4507)(0.98 - 0.4507)$$

$$\underline{\underline{\eta = 94.7\%}}$$

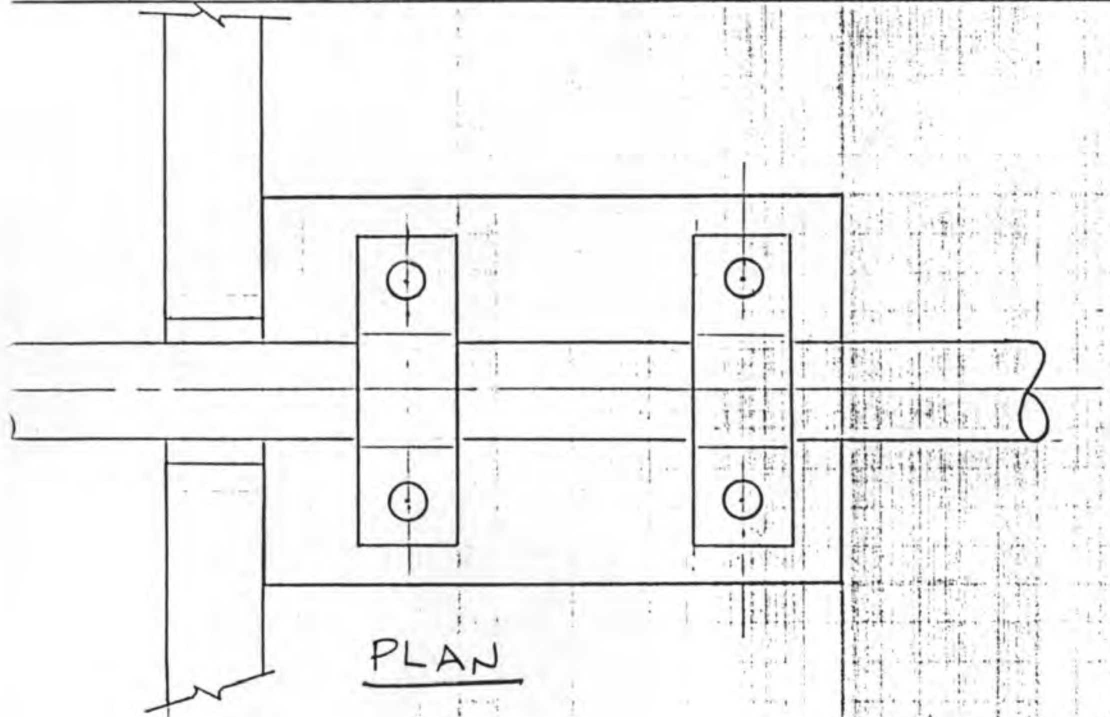
CONCLUSION: This calculation validates the spreadsheet.

ASSUMPTIONS: (1) Calc is steady-state, while there actually exists a transient condition.

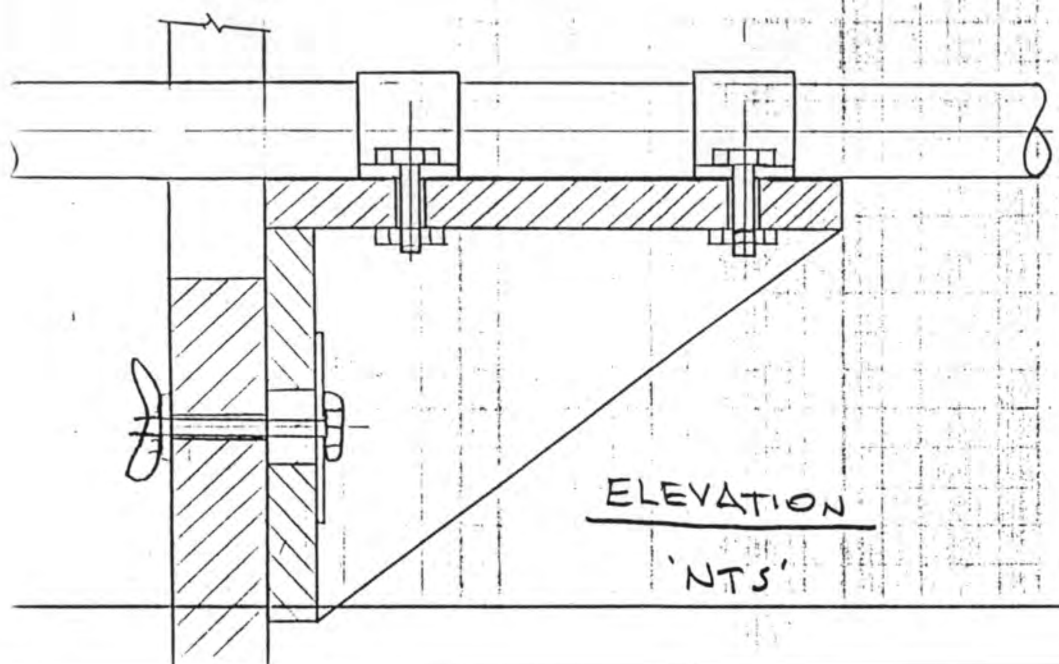
REFERENCES: (1) EIT Ref Manual, 8TH Ed, Lindeburg, pg 17-14

(2) Fluid Mechanics, White

NOZZLE SUPPORT ATTACHMENT



PLAN

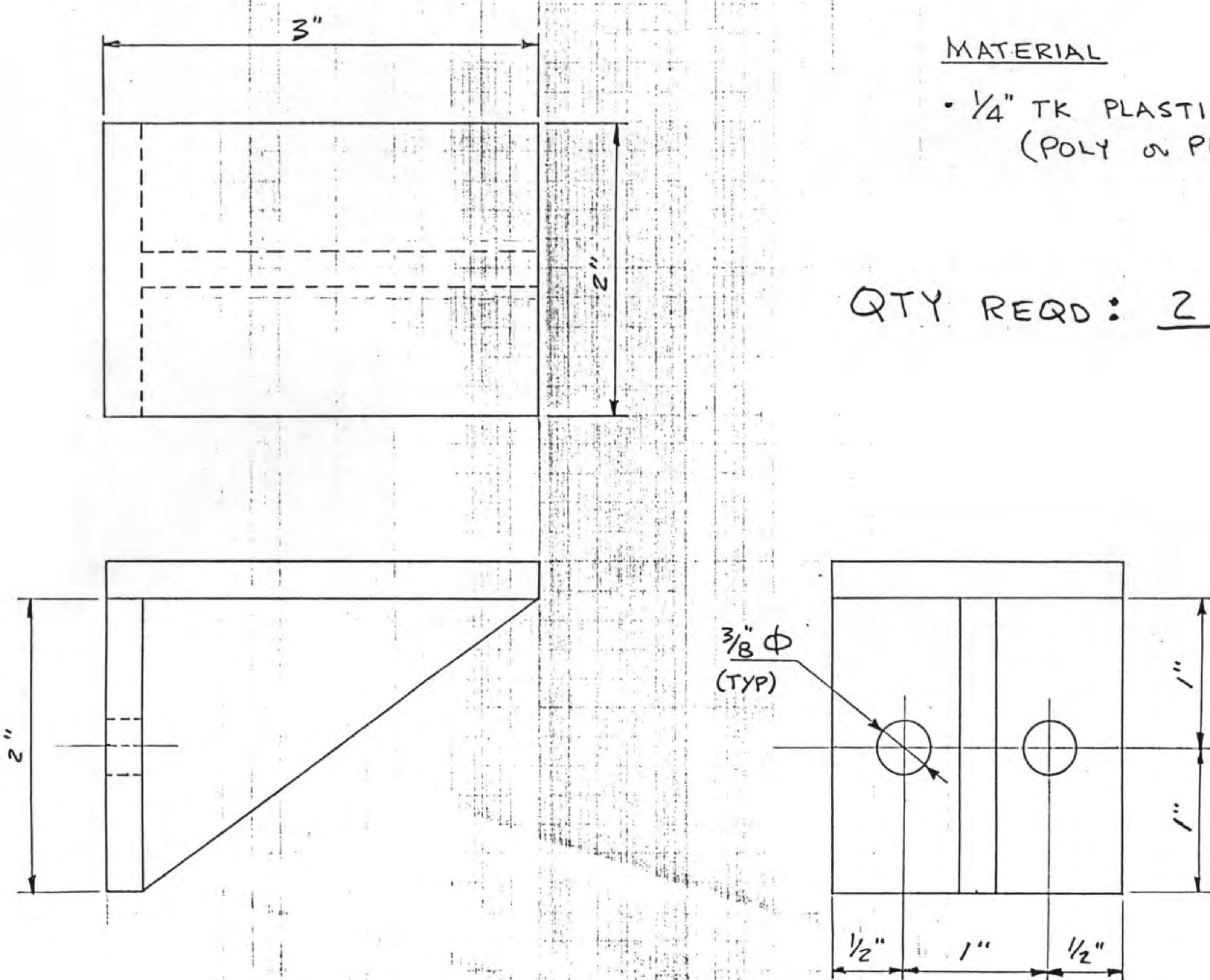


ELEVATION
'NTS'

HARDWARE:

- (4) 1/2" PIPE CLAMPS
- (8) 3/4" x 1/8"Φ bolts w/hex nuts & lock washers
- (4) Lg. Washers 1/4 x 1" OD
- (4) 1 1/2" x 1/8"Φ bolts w/ Lock Washers
- (4) 1/8" Wing nuts

NOZZLE SUPPORT



MATERIAL

- 1/4" TK PLASTIC (POLY or PLEX)

QTY REQD: 2

J.W. Hunt